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The Physicochemistry, Flora, and Fauna of Intermittent Prairie Streams: A Review of the Literature

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Summary

Intermittent streams generally are regarded as poor habitat for fish and wildlife and have received little protection or consideration in land-use planning. Accordingly, many of these habitats have been modified by channelization, removal of riparian vegetation, grazing, and construction of headwater impoundments. Fish and Wildlife Service concern for better understanding of intermittent streams and their importance in the dynamics of Great Plains ecosystems resulted in this literature survey.

Physicochemical characteristics are often less stable in intermittent streams than in nearby perennial reaches and are correlated with flow. This inherent instability results in larger effects from perturbations (e.g., effluents, siltation, removal of shade) on intermittent streams than on perennial streams because conditions in intermittent streams regularly approach physiological tolerance limits of the organisms. Slight perturbations may cause tolerances to be exceeded.

Decomposition is slow in ephemeral headwaters of prairie streams because of the frequent absence of water, but such areas retain detritus and export little organic matter. Decomposition in lower, intermittent reaches exceeds that in ephemeral headwaters but not in perennial streams; detrital inputs in perennial streams are much larger. Storm flows can result in export of much undecomposed organic matter to receiving systems. Removal of natural retention structures (e.g., debris dams) by clearing and snagging or channelization may reduce decomposition of organic matter by native biota and thereby degrade downstream water quality.

The flora of intermittent streams is largely unstudied and inconspicuous. Submerged macrophytes are essentially absent, probably due to high turbidities, unstable substrates, periodically high water velocities, or frequent dewatering. Conversely, emergent aquatic and invasive terrestrial vegetation is common and abundant along many intermittent streams. Microalgae are probably the most important primary producers in intermittent streams and, along with allochthonous detrital inputs, compose the trophic base of these systems.

Macroinvertebrates dominate intermittent streams. Virtually all biological processes of intermittent streams involve or are mediated by macroinvertebrates. Insects, crustaceans, annelids, and molluscs are the dominant taxa. Few species are restricted to intermittent streams, but several taxa that are absent from perennial streams are present in intermittent systems. Macroinvertebrate assemblages are less diverse and stable in intermittent streams than in perennial streams, but higher densities often exist in the former, perhaps as a result of decreased predation or competition. Invertebrates reestablish rapidly in intermittent streams following drought, provided they have opportunities for surviving dry periods (e.g., permanent pools, damp areas under rocks or leaf litter, moist substrates). Accordingly, permanent pools, riparian vegetation, and low silt loads that otherwise fill interstitial spaces in the substrate are vital to the survival of many invertebrates inhabiting intermittent streams.

Fish assemblages of intermittent streams are dominated by high abundances of relatively few species that are highly tolerant of variable and extreme physical conditions. Abundances of popular sport fishes are typically low. Some species inhabit intermittent streams temporarily for spawning or during periods of high flow, and some evidence suggests that intermittent streams may be important nursery areas before cessation of flow. Large permanent pools are the most important feature of intermittent streams with respect to fishes. Manipulations that decrease size or frequency of permanent pools decrease habitat availability and stability and deleteriously affect fish assemblages in intermittent streams. Similarly, removal of riparian vegetation from banks decreases shading and promotes instability through wider extremes of temperature.

Little published information addresses the specific importance of intermittent streams as wildlife habitats, but comparisons between habitats along intermittent streams and those of riparian communities along perennial waterways are possible given similar physiognomic and ecological characteristics of the vegetation. Riparian areas are critical wildlife habitats for the following reasons: (1) they provide a permanent or seasonal source of water; (2) soil moisture is increased and plant biomass is typically greater than in surrounding communities, which increases structural diversity; (3) interspersion of riparian and upland communities can maximize wildlife diversity (i.e., edge effect); (4) they provide greater diversity of microhabitats, including wildlife breeding and feeding sites; and (5) they constitute important movement and migratory corridors. Pernicious influences include road and campground construction, extensive grazing by livestock, uncontrolled logging, and alterations to stream flow (e.g., diversion for irrigation, impoundments, or channelization).

Intermittent streams are unique habitats essential to the structure and function of ecosystems of the southern Great Plains. Their presence is critical to fish and wildlife populations in the region, an area where perennial streams are rare and widely separated. Modification of intermittent streams by channelization, removal of riparian vegetation, grazing, construction of headwater impoundments, siltation, and domestic and industrial effluents is highly deleterious to these sensitive habitats and their biota and significantly degrades the quality of

adjacent terrestrial habitats. Accordingly, these perturbations insidiously affect the quality of human life in the region. Enhanced protection of intermittent streams is an essential component of natural resource management in the southern Great Plains, especially in consideration of the neglect of these critically important habitats in past and present land-use planning.

Preface

This review was prepared at the request of the U.S. Fish and Wildlife Service Regional Director, Albuquerque, New Mexico, and the Supervisor and staff of the Ecological Services Field Office, Tulsa, Oklahoma. It provides a single-source reference useful for evaluation of current status of intermittent prairie streams, particularly in Oklahoma. It also provides guidelines for evaluating the potential effects of changing watershed land use and other human-related activities on the physical nature, floral and faunal resources, and overall values of this now relatively limited habitat. This report is an introduction and entry to the relevant literature, but it is not intended as a substitute for reference to original material.

Any questions, comments, or suggestions regarding this publication should be directed to:

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Introduction

Many small streams in the Great Plains of the south-central United States cease to flow during part of the year. In these intermittent streams water remains only in permanent pools, whereas ephemeral streams are completely dry for most of the year. Both types of streams generally are regarded as poor habitat for fish and wildlife and have received little protection or consideration in land-use planning despite their legal status as navigable waters (Wright 1981). This lack of concern has resulted in many of these habitats being modified by channelization, removal of riparian vegetation, grazing, and construction of headwater impoundments.

Interest in these habitats has renewed in recent years, as biologists and managers question the assumption that intermittent streams are unimportant to fish and wildlife. Typical inquiries include the following:

1. What importance do intermittent streams have to game and forage fish populations, and how do these populations interrelate and compare with those in perennial systems?
2. What is the importance of permanent pools of intermittent streams to aquatic and terrestrial organisms and streamside vegetation?
3. What effects do common human-induced manipulations such as channelization, draining, clearing-snagging, grazing, and impoundment have on aquatic and terrestrial organisms and streamside vegetation of intermittent streams?
4. What is the importance of upstream fish fauna to downstream fish and wildlife in other, adjacent, low-order streams? Especially, what percent of the forage fish is derived from low-order streams?
5. What comparisons can be made between fish production in low-order intermittent streams versus higher-order perennial systems?
6. What is the relation between adjacent vegetation and land use on the productivity, species composition, and so forth, of intermittent streams?
7. Are there long-term shifts in riparian vegetation adjacent to intermittent streams?
8. If permanent pools are removed either by mechanical means or temporarily by drought, how long will it take for faunal reestablishment?
9. How do migratory birds use intermittent streams?
10. What is the annual variation in richness and abundance of invertebrates in intermittent streams?

We produced this literature survey because of a general concern for better understanding of intermittent streams and their role in the dynamics of Great Plains

ecosystems. Unfortunately, most of the above questions cannot be answered definitively because of the paucity of applied research on intermittent streams. Nevertheless, some inferences are possible from the few ecological studies on intermittent streams and from research conducted on perennial habitats. Personnel evaluating effects on intermittent streams should consult references pertaining to those same circumstances on perennial streams and modify their conclusions using information from the references cited herein. In general, disturbances on intermittent streams are analogous to those affecting perennial streams, but may involve different species assemblages and may be more severe because intermittent streams are less stable systems.

This document has six sections: Physicochemical Characteristics, Community Production and Respiration, Plants, Invertebrates, Fishes, Wildlife, and Conclusions. The first five sections have a summary of findings pertinent to this review followed by a geographic listing of reference annotations. The chapter on wildlife has no specific reference annotations because few pertinent references exist. Instead, the chapter consists of our interpretation of the importance of intermittent streams to wildlife.

Physicochemical Characteristics

Summary

The physical and chemical properties of intermittent streams are as varied as the climates and geologies of the localities where the streams are found. Generalizations are impossible except that instability of physicochemical characteristics is often much greater in intermittent streams than in nearby perennial reaches and is correlated with flow. Streams, in general, are more variable than lakes because they contain less water per unit area and are more closely linked to geological features and the atmosphere; continuity of flow tends to moderate this variability to some degree. However, cessation of flow renders intermittent streams highly vulnerable to environmental influences.

The inherent instability of physicochemical characteristics of intermittent streams also results in vulnerability to perturbations such as effluents, siltation, and removal of shade – more so than perennial streams. The increased variability and range in physicochemical conditions characteristic of intermittent streams render them unsuitable habitat for some intolerant species that are adapted to more stable conditions. Accordingly, biologists tend to consider intermittent streams harsh and environmentally rigorous habitats. Perturbations considered relatively minor to perennial streams can have severe effects on the biota of these unstable and sensitive habitats.

Reference Annotations

Arizona

Lewis and Burraychak (1979) studied an intermittent stream in central Arizona that was affected by effluents from an open-pit copper mine (Table 1). Fish and macroinvertebrate assemblages and primary production rates below outfalls were drastically reduced by increased heavy-metal concentrations and suspended solids.

Australia

Towns (1985) presented physicochemical and invertebrate data collected over a 3-year period in intermittent Brown Hill Creek, near Adelaide, South Australia. The stream typically ceased to flow for about

Table 1. *Physicochemical conditions in an intermittent stream in central Arizona affected by effluents from an open-pit copper mine (Lewis and Burraychak 1979).*

Physicochemical variable	Mean value	
	Above outfall	Below outfall
pH	7.7	8.0
Total hardness as $CaCO_3$ (mg/L)	254	752
Total alkalinity as $CaCO_3$ (mg/L)	56	178
Suspended solids (mg/L)	0	2
Conductivity (μmhos/cm)	1,007	1,544
Ca (mg/L)	54	223
Mg (mg/L)	23	11
Na (mg/L)	21	51
Fe (mg/L)	<0.05	0.22
Cu (mg/L)	<0.05	0.09
Mn (mg/L)	<0.05	0.30
Zn (mg/L)	<0.05	0.14
SO_4 (mg/L)	158	670

6 months annually, generally from December or January through May or June. The stream was in a eucalyptus (*Eucalyptus obliqua*) forest; accordingly, leaf fall did not occur in autumn, but rather during summer drought from January through March. Water temperature in a permanent pool declined to about 10°C by May each year and changed little until early spring. During summer, water temperature rose to a maximum of 25°C, but more commonly varied from 15 to 20°C. Maximum conductivity and minimum pH usually occurred at the onset of flow, and minimum conductivity and maximum pH (near neutral) were recorded during summer when flow had ceased. An exception occurred when high conductivities were recorded during summer when air temperature exceeded 38°C for 7 consecutive days. Dissolved oxygen concentrations declined rapidly following cessation of flow, reaching a minimum of 0.3 mg/L in a permanent pool. Levels remained low until fall, but gradually increased until flow commenced and oxygen saturation occurred. Water color in permanent pools was a purple-black color during summer and apparently resulted from the interaction between leaf litter accumulation and low oxygen concentrations.

Indiana

Depletion of dissolved oxygen in fall in a south-central Indiana stream was described by Schneller (1955). Coincident with leaf fall and low flows, dissolved oxygen concentrations declined to 0.3 mg/L in late October and early November. Concurrently, free carbon dioxide concentrations increased, and water color was inky-black. High biological oxygen demand resulting from accumulation of leaf litter was implicated as the cause.

Fish mortality was not observed, but fish congregated below a riffle where oxygen concentrations were 2.4–2.6 mg/L higher than above the riffle. Also, low water temperatures (about 10°C) may have elevated oxygen concentrations in the surface film; water samples were taken 15 cm below the surface. Anecdotal information suggested that the phenomenon deleteriously affected angling. In a smaller nearby stream, fall mortality of several dozen spotted suckers[1], highfin carpsuckers, and longear sunfish were observed in an earlier year when the duration of water discoloration was extended. [Although the stream was not intermittent – some current was perceptible in riffle areas – the phenomenon is probably common in intermittent streams.]

Kansas

The Kansas Department of Health and Environment (1981) determined the effects of floodwater-retarding impoundments on the biota and water quality of intermittent streams in Kansas. Curtailed funding precluded a comprehensive and detailed analysis of the data, but preliminary analyses suggested that impoundments influenced downstream turbidity. In previously turbid streams, turbidity was reduced below impoundments when compared to downstream control stations, apparently due to settling in lakes. However, in the Flint Hills where stream turbidities are naturally low, turbidities were higher below impoundments; high organic carbon and chlorophyll concentrations below these impoundments suggested that the higher turbidities were caused by phytoplankton flushed from the impoundments. Silicon concentrations and total alkalinities were reduced below impoundments.

Ohio

Water temperatures and dissolved oxygen concentrations during summer drought were monitored by Tramer (1977) in six small pools of a 1st-order intermittent stream in Ohio. Water temperatures varied from 15.5 to 20.5°C at dawn and from 22.5 to 32.0°C in the afternoon. Early in the study, dissolved oxygen concentrations varied from 1.0 to 3.8 mg/L at dawn and increased to 8 to 9 mg/L in the afternoon, presumably as a result of algal photosynthesis. As the pools shrank, afternoon dissolved oxygen concentrations levels declined, and overall the pools exhibited little diurnal variability as they evaporated.

Oklahoma

Physicochemical conditions in the Otter Creek drainage basin of north-central Oklahoma were monitored by Harrel and Dorris (1968). The stream was a 6th-order, intermittent system. The basin was in a mixed-grass prairie association and much of the land was cultivated or pastured. Annual precipitation averaged 81 cm. Cover varied from open, unshaded banks in the headwaters to densely tree-lined banks in high-order reaches. Sands, clays, and silts were dominant substrates, but gravel and cobbles were present in restricted reaches. Physicochemical fluctuations decreased as stream order increased (Table 2). Mean volume of stream flow increased with stream order. Only a trace of flow was evident near the mouth of the creek during July and August, and most 3rd- and 4th-order sites and one 5th-order site were dry in August. During spring and fall, flow was continuous below 4th-order sites. During winter, the season of least precipitation, flow was continuous at all sites except some 3rd-order stations where flow was observed for short periods only during or directly after rainfall. Increased flow during winter was attributed to lower evaporation, decreased plant activity, and a higher groundwater table.

Turbidity decreased and conductivity increased as stream order increased. Turbidity was low and

[1]Scientific and common names of fishes mentioned in the text are provided in the Appendix.

Table 2. *Ranges of physicochemical conditions by stream order in Otter Creek, Oklahoma, a 6th-order intermittent stream (Harrel and Dorris 1968).*

Physicochemical variable	Stream order			
	3	4	5	6
Temperature (°C)	2–39	1–34	1–3	31–26
pH	6.8–9.8	7.4–9.4	7.2–8.5	7.4–8.4
Alkalinity HCO_3 (mg/L)	39–341	69–276	57–296	78–294
Alkalinity CO_3 (mg/L)	0–219	0–180	0–42	0–24
Dissolved oxygen (mg/L)	0.6–17.5	2.4–17.3	1.0–13.1	5.3–12.3
Turbidity (mg/L)	8–310	11–310	10–310	11–310
Conductivity (μmhos/cm)	120–1,640	178–1,412	184–2,104	210–1,163
Discharge (cm)	0–0.006	0–0.08	0–0.17	0–0.32

conductivity was high in winter; the reverse was true in fall. Intermediate turbidities and conductivities were recorded in spring and summer. Streams were rich in carbonates and bicarbonates, which was conducive to high productivity. Bicarbonates increased and carbonates decreased in the higher stream orders. Variation in pH and dissolved oxygen concentrations decreased as stream order increased. High dissolved oxygen concentrations and pH values were associated with algal blooms, and pools littered with allochthonous plant debris had low dissolved oxygen and pH values. Mean annual water temperature decreased as stream order increased; the largest daily, seasonal, and annual fluctuations were among 3rd-order stations and decreased as stream order increased, largely because of differences in shading and time of sampling. Allochthonous plant debris increased with woody riparian vegetation and concomitantly with increasing stream order.

Mathis and Dorris (1968) monitored physicochemical conditions in Black Bear Creek, an intermittent stream in north-central Oklahoma that received oilfield brines. Turbidity was inversely correlated with brine concentration and was highest in summer and lowest in winter. High turbidity in summer was caused by increased flow and dilution of brines. Low turbidity in winter was attributed to higher ion concentrations, low precipitation, and decreased turbulence. Seasonal variation in conductivity was minimal (slightly higher in winter), but was greatly altered longitudinally by influxes of brines; conductivities varied from 16,000 μmhos/cm below the brine outfall to 231 μmhos/cm 80 km downstream. Higher conductivity during winter was attributed to a more uniform distribution of brines downstream resulting from infrequent precipitation and stable discharge. Heavy rains in other seasons diluted brines except immediately below their discharge. During periods of low discharge, water from tributaries diluted brines, which resulted in decreased conductivity and increased turbidity as distance from the outfall increased. Dissolved oxygen concentrations measured during daylight hours varied from 3.7 mg/L in the headwaters to 12.1 mg/L in lower reaches of the stream. [No information was provided on the date or number of oxygen determinations.]

In a study of diel variation of phytoplankton in an intermittent Oklahoma stream, Mahnken and Wilhm (1982) measured water quality over four 24-h periods (Table 3). Maximum temperatures and dissolved oxygen concentrations occurred at 1700 h; minimum dissolved oxygen concentrations occurred at 0500 h. The relatively small diel variation in dissolved oxygen concentration was probably a result of high turbidity that caused decreased oxygen production by phytoplankton and benthic algae.

Data collected by Jerry Wilhm and associates (Department of Zoology, Oklahoma State University) for impact assessment of the Sooner Generating Station in north-central Oklahoma constitute the largest and most com-

Table 3. *Diel ranges of physicochemical conditions in Otter Creek, Oklahoma (Mahnken and Wilhm 1982).*

Physicochemical variable	28 June 76	11 June 77	11 July 77	20 August 77
Temperature (°C)	4.0–9.9	4.1–7.0	3.8–4.3	4.0–5.2
pH	24.5–31.5	24.5–30.5	26.0–31.5	23.0–29.0
Dissolved oxygen (mg/L)	1,245–1,390	850–925	270–300	340–370
Conductivity (μmhos/cm)	7.9–8.5	7.6–7.9	7.7–7.8	7.3–7.8

plete single body of physicochemical information available on intermittent streams. Monthly or quarterly samples were collected at five sites on three intermittent streams (Greasy, Red Rock, and Unnamed creeks) for 1 year. Because of the limited availability of the pertinent report (Benham-Blair & Affiliates, Inc. 1976), we present these data in Tables 4–8. Water quality in the three creeks varied considerably with flow. For example, high levels of dissolved solids, alkalinity, ammonia, dissolved oxygen, chlorides, hardness, and conductivity occurred during periods of low flow. Generally, water quality was low because of high concentrations of dissolved solids and high turbidities. Dissolved solids probably originated from natural salt deposits and oil-pumping activities. Levels exceeded the maximum recommended for drinking water and irrigation. Suspended material contributing to turbidity originated primarily from erosion in the watershed, although some suspended material consisted of planktonic bacteria and algae, especially when flow was low. High nutrient concentrations and coliform numbers were believed to reflect runoff from feedlots and croplands; contamination from domestic sewage was not apparent. Significant pesticide contamination was not found. Most heavy metals were at or below detection levels.

South Dakota

McCoy and Hales (1974) surveyed stream headwaters on the eastern side of the Coteau de Prairies, South Dakota. Of 110 streams surveyed, only 6 were perennial. Physical and chemical characteristics of eight streams were measured in May 1973 when flow was present in all streams (Table 9).

Texas

In conjunction with a fish survey, Whiteside and McNatt (1972) determined physicochemical conditions in the Plum Creek drainage basin of south-central Texas. Plum Creek is a 5th-order intermittent stream that empties into the San Marcos River. Physicochemical conditions were measured from January through April 1968 (Table 10). At the time of sampling, water was present in only a few 1st-order streams; most 2nd- and 3rd-order and all 4th- and 5th-order streams contained water. Mean dissolved oxygen concentrations decreased regularly with increasing stream order; the extreme lows in the low-order streams were associated with oil fields or domestic sewage. Mean pH values and total alkalinities did not vary significantly with stream order but ranges of value decreased with increasing stream order; low pH values were associated with oil fields, and the extremely high total alkalinity (443 mg/L) in a 3rd-order stream was in an urban setting. Mean turbidities and conductivities increased with increasing stream order through 4th-order streams, but decreased in the 5th-order reach.

Ranges of physicochemical conditions at a permanent pool on intermittent Aquilla Creek, Texas, from March to December 1980 (Campbell and Clark 1982) are presented in Table 11. Substrate at the intermittent site was composed of silty mud, clay, and leaves. Appearance of the water was "turbid to green."

Community Production and Respiration

Summary

Headwaters of streams have traditionally been considered heterotrophic (i.e., community respiration exceeds production) because seminal studies of stream metabolism were conducted in forested regions. Within forests, riparian vegetation shades streams and contributes large amounts of allochthonous leaf litter (Vannote et al. 1980); accordingly, primary production (autotrophy) within forested streams is small when compared to allochthonous inputs (heterotrophy). However, in prairie ecosystems canopies are open, insolation is high, and litter inputs are low. Primary production by benthic algae produces most of the organic material. Therefore, headwaters of intermittent streams in the plains tend to be autotrophic except perhaps where turbidities are high. Lower reaches of intermittent prairie streams, which are lined with riparian gallery forests, are probably heterotrophic.

Avenues and rates of import, storage, decomposition, and export of organic matter are significant determinants of downstream water quality. Decomposition in ephemeral headwaters of prairie streams is slow because of the frequent absence of water, but such areas retain detritus and export little organic matter. Decomposition in lower, intermittent reaches is faster than in the ephemeral headwaters, but not as rapid as in perennial streams, but detrital inputs there are much larger. Storm flows can export much undecomposed organic matter to receiving systems. Decomposition in intermittent streams seems to be dominated by microbial, fungal, and physical factors. Shredding invertebrates, which are instrumental in decomposition processes in perennial headwater streams, seem to be relatively unimportant. Rigorous physical conditions may preclude development of a rich shredder assemblage.

Reference Annotations

Arizona

Effects of effluents from open-pit copper mines on the biota of an intermittent stream in central Arizona were documented by Lewis and Burraychak (1979). In June, primary production was 5.3 g O_2/m^2/day and community respiration was 4.3 g O_2/m^2/day for an unpol-

Table 4. *Water quality data for upstream station,*

Variable	January	February	March	April
Temperature (°C)	2.0	1.0	11.0	15.5
pH	8.9	8.3	7.8	8.1
Hardness, total (mg/L $CaCo_3$)	328	147	268	1,010
Hardness, calcium (mg/L $CaCo_3$)	270	94	83	401
Alkalinity (mg/L $CaCo_3$)	220	97	136	272
Dissolved oxygen (mg/L)	13.0	11.0	9.4	10.2
Turbidity (JTU)	—	260	390	22
Conductivity (μmhos/cm)	2,176	836	1,012	4,482
Velocity (m/sec)	—	—	—	0.03
Flow (m^3/sec)	0.06	0.34	0.34	0.06
Boron (μg/L B)	90	40	80	115
Chloride (mg/L Cl)	510	104	221	1,269
Nitrate (mg/L NO_3)	3.10	1.77	0.62	0.04
Ortho-Phosphate (mg/L PO_4)	0.15	0.12	0.12	0.06
Silica (mg/L SiO_2)	10.0	11.4	9.0	6.0
Sulfate (mg/L SO_4)	18	3	18	24
Color (standard units)	10	220	175	38
Total solids (mg/L)	1,365	445	789	1,533
Dissolved solids (mg/L)	1,323	359	665	1,367
Oil and grease (mg/L)	2.1	3.0	0.3	1.1
Oil and grease, surface (mg/L)	1.9	4.1	0.6	3.3
COD (mg/L)	21.6	21.2	32.2	13.8
BOD_5 (mg/L)	4.5	3.0	2.7	1.3
Total coliform (100 mL)	50	450	317	233
Fecal coliform (100 mL)	30	50	317	0
Fecal streptococcus (100 mL)	20	167	317	0
Iron, dissolved (mg/L Fe)			0.1	
Iron, suspended (mg/L Fe)			7.9	
Lead, dissolved (mg/L Pb)			<0.005	
Lead, suspended (mg/L Pb)			0.016	
Manganese, dissolved (mg/L Mn)			<0.05	
Manganese, suspended (mg/L Mn)			0.26	
Magnesium, dissolved (mg/L Mg)			18.7	
Magnesium, suspended (mg/L Mg)			1.0	
Zinc, dissolved (mg/L Zn)			0.01	
Zinc, suspended (mg/L Zn)			0.05	
Copper, dissolved (mg/L Cu)			<0.05	
Copper, suspended (mg/L Cu)			<0.05	
Chromium, dissolved (mg/L Cr)			<0.005	
Chromium, suspended (mg/L Cr)			0.023	
Silver, dissolved (mg/L Ag)			<0.01	
Silver, suspended (mg/L Ag)			<0.01	
Sodium, dissolved (mg/L Na)			120.3	
Sodium, suspended (mg/L Na)			<5.0	
Calcium, dissolved (mg/L Ca)			57.0	
Calcium, suspended (mg/L Ca)			<0.4	
Potassium, dissolved (mg/L K)			4.9	
Potassium, suspended (mg/L K)			0.8	
Mercury, total (mg/L Hg)			<0.0005	
Selenium, total (mg/L Se)			<0.005	
Organochlorines, water (μg/L)			ND[a]	
Organochlorines, sediment (μg/L)			ND	
Organophosphates, water (μg/L)			ND	
Organophosphates, sediment (μg/L)			ND	
Chlorine, free (mg/L)			ND	
Cyanide (μg/L)			ND	
Ammonia (μg/L)			4.77	

[a] ND = Not detected.

Greasy Creek, Oklahoma, 1975 (Benham-Blair & Affiliates, Inc. 1976).

May	June	July	August	September	October	November	December
16.0	29.0	22.5	21.5	17.5	17.0	9.0	3.5
7.5	7.9	7.6	7.4	7.0	7.2	7.4	7.9
185	364	780	1,625	1,034	1,064	404	400
80	103	128	245	527	690	260	246
92	144	174	129	104	146	252	219
8.2	6.3	5.3	2.9	5.1	2.3	7.0	7.0
700	75	20	25	50	120	25	18
780	1,840	6,604	9,072	4,610	5,940	2,025	1,886
0.08	0.04	0	0	0	0	0	0
0.06	0.34	0.20	0	0	0	0	0
60	105	250	250	220	205	215	200
148	483	2,524	2,980	1,450	1,812	492	527
0.49	0	0.04	0	0	0	0	0.18
0.12	0.30	0.03	0.06	0.18	0.18	0	0.06
10.0	9.2	11.6	3.6	1.9	5.0	3.6	3.6
7	11	6.5	17	19	20	78	21
720	80	20	30	40	50	60	10
761	1,303	4,817	5,531	3,578	4,751	1,098	1,293
531	1,253	4,783	5,513	3,534	4,683	1,088	1,073
3.5	4.5	6.4	4.0	3.4	4.5	4.3	4.8
3.3	6.2	3.7	4.2	15.6	5.2	6.6	4.9
15.6	10.1	4.5	23.7	64.5	55.2	14.7	20.2
2.5	2.7	5.2	2.6	3.7	4.8	0.6	1.8
3,933	1,400	4,933	300	200	900	0	433
2,833	300	5,066	0	100	300	0	0
5,067	133	2,500	833	100	100	233	0
	<0.10			<0.01			<0.01
	2.32			2.08			0.32
	0.013			0.002			<0.001
	0.023			<0.001			0.009
	<0.10			<0.01			<0.10
	<0.10			<0.01			<0.10
	26.71			74.93			<0.10
	<0.10			<0.10			<0.10
	<0.01			<0.01			<0.01
	0.028			<0.01			<0.01
	<0.05			<0.05			<0.01
	<0.05			<0.05			<0.01
	0.022			0.009			0.008
	0.029			0.010			0.018
	<0.01			<0.01			<0.01
	<0.01			<0.01			<0.01
	230.8			510.0			266.6
	<5.0			<5.0			<5.0
	111.78			2.64			81.49
	<0.10			<0.10			<0.10
	6.23			7.79			9.44
	<0.10			0.53			<0.01
	<0.0003			<0.0003			<0.0003
	0.010			<0.005			<0.005
	ND			ND			ND
	<0.01 lindane			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	2.23			2.08			0.91

Table 5. *Water quality data for downstream station,*

Variable	January	February	March	April
Temperature (°C)	2.0	0.75	11.5	16.0
pH	8.2	8.2	8.1	8.1
Hardness, total (mg/L $CaCo_3$)	322	221	298	422
Hardness, calcium (mg/L $CaCo_3$)	295	176	123	260
Alkalinity (mg/L $CaCo_3$)	263	198	200	322
Dissolved oxygen (mg/L)	12.9	11.1	9.4	8.8
Turbidity (JTU)	—	142	169	85
Conductivity (μmhos/cm)	1,348	1,419	1,048	1,458
Velocity (m/s)	—	—	—	0.03
Flow (m^3/s)	0.17	0.17	0.40	0.14
Boron (μg/LB)	150	60	80	145
Chloride (mg/L Cl)	205	188	186	205
Nitrate (mg/L NO_3)	1.77	1.55	0.07	0.53
Ortho-Phosphate (mg/L PO_4)	0.24	0.30	0.03	0.09
Silica (mg/L SiO_2)	12.8	12.2	10.8	12.3
Sulfate (mg/L SO_4)	46	10	29	38
Color (standard units)	10	125	170	50
Total solids (mg/L)	796	603	658	924
Dissolved solids (mg/L)	757	554	570	824
Oil and grease (mg/L)	2.5	0	0.1	3.4
Oil and grease, surface (mg/L)	3.1	0.4	0.1	2.9
COD (mg/L)	14.0	13.3	27.5	15.9
BOD_5 (mg/L)	2.2	3.0	4.0	1.8
Total coliform (100 mL)		183	450	267
Fecal coliform (100 mL)	—	200	150	167
Fecal streptococcus (100 mL)	20	350	333	133
Iron, dissolved (mg/L Fe)			0.1	
Iron, suspended (mg/L Fe)			4.2	
Lead, dissolved (mg/L Pb)			<0.005	
Lead, suspended (mg/L Pb)			0.006	
Manganese, dissolved (mg/L Mn)			<0.05	
Manganese, suspended (mg/L Mn)			0.30	
Magnesium, dissolved (mg/L Mg)			20.6	
Magnesium, suspended (mg/L Mg)			0.3	
Zinc, dissolved (mg/L Zn)			<0.01	
Zinc, suspended (mg/L Zn)			0.04	
Copper, dissolved (mg/L Cu)			<0.05	
Copper, suspended (mg/L Cu)			<0.05	
Chromium, dissolved (mg/L Cr)			<0.005	
Chromium, suspended (mg/L Cr)			0.019	
Silver, dissolved (mg/L Ag)			<0.01	
Silver, suspended (mg/L Ag)			<0.01	
Sodium, dissolved (mg/L Na)			120.3	
Sodium, suspended (mg/L Na)			<5.0	
Calcium, dissolved (mg/L Ca)			68.5	
Calcium, suspended (mg/L Ca)			0.9	
Potassium, dissolved (mg/L K)			4.0	
Potassium, suspended (mg/L K)			0.1	
Mercury, total (mg/L Hg)			<0.0005	
Selenium, total (mg/L Se)			<0.005	
Organochlorines, water (μg/L)			ND[a]	
Organochlorines, sediment (μg/L)			ND	
Organophosphates, water (μg/L)			ND	
Organophosphates, sediment (μg/L)			ND	
Chlorine, free (mg/L)			ND	
Cyanide (μg/L)			ND	
Ammonia (μg/L)			2.23	

[a] ND = Not detected.

Greasy Creek, Oklahoma, 1975 (Benham-Blair & Affiliates, Inc. 1976).

May	June	July	August	September	October	November	December
18.0	24.5	20.5	24.5	17.0	18.8	12.0	5.0
7.0	7.9	7.4	7.5	7.4	7.3	7.6	7.9
129	271	632	735	660	370	227	328
49	116	86	230	362	248	192	223
88	160	392	350	322	362	296	308
7.1	6.0	4.1	5.3	4.5	0.9	3.1	5.2
400	120	35	55	47	51	108	25
317	1,232	2,420	2,505	1,871	941	751	979
0	0	0.03	0	0	0	0	0
0	0	0.14	0	0	0	0	0
50	75	220	235	190	120	145	145
21	226	480	615	425	130	51	97
0.09	3.43	0.97	0.22	0	0	0	0.11
0.15	0.70	0.18	0.12	0.18	0.47	0.40	0.55
12.2	10.0	14.0	10.3	13.8	20.8	12.2	18.8
7	106	50	105	71	40	100	54
340	70	30	30	30	50	60	90
365	819	1,729	1,718	1,417	646	479	551
261	735	1,681	1,652	1,396	623	425	528
6.3	4.1	8.2	5.5	5.4	4.0	4.4	3.4
4.3	4.5	4.1	4.8	4.1	4.7	5.7	8.6
16.0	4.0	3.5	15.8	26.0	14.8	11.3	13.5
3.1	0.7	3.1	5.1	4.9	3.5	2.8	2.7
5,000	1,667	967	100	100	67	567	67
4,100	467	233	0	0	67	367	33
6,267	433	100	67	233	67	0	100
	<0.10			<0.05			<0.01
	6.16			1.81			0.82
	0.022			<0.001			0.001
	0.040			0.004			<0.001
	<0.10			2.36			<0.10
	<0.10			<0.01			<0.10
	17.57			37.11			<0.10
	<0.10			<0.10			<0.10
	<0.01			<0.01			<0.010
	0.33			<0.01			0.023
	<0.05			<0.05			<0.010
	<0.05			<0.05			0.036
	0.015			0.011			0.004
	0.017			0.014			0.009
	<0.01			<0.01			<0.01
	<0.01			<0.01			<0.01
	172.3			136.5			77.6
	<5.0			<5.0			<5.0
	85.75			1.26			59.80
	<0.10			<0.10			<0.10
	8.58			6.19			5.81
	1.01			0.53			0.56
	<0.0003			0.0006			<0.0003
	0.010			<0.005			<0.005
	ND			ND			ND
	ND			ND			ND
	ND			ND			0.1 Thionazin, Diazinon
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	1.51			0.60			1.04

Table 6. *Water quality data for Unnamed Creek,*

Variable	January	February	March	April
Temperature (°C)	2.0	1.0	12.0	16.0
pH	8.4	7.8	8.5	8.2
Hardness, total (mg/L $CaCo_3$)	545	328	418	750
Hardness, calcium (mg/L $CaCo_3$)	473	244	268	400
Alkalinity (mg/L $CaCo_3$)	310	156	218	321
Dissolved oxygen (mg/L)	13.4	11.0	9.2	10.7
Turbidity (JTU)	—	114	105	5
Conductivity (μmhos/cm)	4,011	2,613	2,110	4,785
Velocity (m/s)	—	—	—	0.06
Flow (m^3/s)	0.03	0.06	0.11	0.03
Boron (μg/L B)	105	50	80	115
Chloride (mg/L Cl)	908	452	497	1,354
Nitrate (mg/L NO_3)	0.44	1.77	0	0
Ortho-Phosphate (mg/L PO_4)	0.09	0.25	0.03	0.03
Sulfate (mg/L SO_4)	48	10	34	34
Color (standard units)	0	80	150	30
Total solids (mg/L)	2,125	1,102	1,249	3,131
Dissolved solids (mg/L)	2,114	1,035	1,211	3,101
Oil and grease (mg/L)	3.3	0.7	0.2	6.0
Oil and grease, surface (mg/L)	2.7	0.8	0.1	4.2
COD (mg/L)	7.6	16.4	26.3	10.6
BOD_5 (mg/L)	2.0	3.4	3.2	0.8
Total coliform (100 mL)	20	583	267	567
Fecal coliform (100 mL)	—	317	217	333
Fecal streptococcus (100 mL)	10	283	200	33
Iron, dissolved (mg/L Fe)			0.1	
Iron, suspended (mg/L Fe)			2.4	
Lead, dissolved (mg/L Pb)			<0.005	
Lead, suspended (mg/L Pb)			0.017	
Manganese, dissolved (mg/L Mn)			0.13	
Manganese, suspended (mg/L Mn)			0.17	
Magnesium, dissolved (mg/L Mg)			26.9	
Magnesium, suspended (mg/L Mg)			<0.2	
Zinc, dissolved (mg/L Zn)			<0.01	
Zinc, suspended (mg/L Zn)			0.03	
Copper, dissolved (mg/L Cu)			<0.05	
Copper, suspended (mg/L Cu)			<0.05	
Chromium, dissolved (mg/L Cr)			<0.005	
Chromium, suspended (mg/L Cr)			0.015	
Silver, dissolved (mg/L Ag)			<0.01	
Silver, suspended (mg/L Ag)			<0.01	
Sodium, dissolved (mg/L Na)			251.6	
Sodium, suspended (mg/L Na)			<5.0	
Calcium, dissolved (mg/L Ca)			94.8	
Calcium, suspended (mg/L Ca)			<0.4	
Potassium, dissolved (mg/L K)			5.4	
Potassium, suspended (mg/L K)			<0.1	
Mercury, total (mg/L Hg)			<0.0005	
Selenium, total (mg/L Se)			<0.005	
Organochlorines, water (μg/L)			ND[a]	
Organochlorines, sediment (μg/L)			ND	
Organophosphates, water (μg/L)			ND	
Organophosphates, sediment (μg/L)			ND	
Chlorine, free (mg/L)			ND	
Cyanide (μg/L)			ND	
Ammonia (μg/L)			2.23	

[a] ND = Not detected.

Oklahoma, 1975 (Benham-Blair & Affiliates, Inc. 1976).

May	June	July	August	September	October	November	December
18.0	24.5	21.0	23.5	16.0	18.0	12.0	2.0
6.9	7.9	7.8	7.8	7.7	7.2	7.6	8.3
132	270	736	1,295	1,480	1,254	1,430	820
48	100	80	260	875	814	1,000	500
85	152	324	263	253	412	405	338
7.2	6.1	7.0	5.0	6.4	0	0	7.9
380	120	20	15	25	163	87	20
303	1,273	4,731	5,449	5,670	5,356	5,877	4,794
0	0	0.03	0	0	0	0	0
0	0	0.03	0	0	0	0	0
60	90	227	190	200	250	190	230
25	237	1,280	1,985	1,750	1,688	1,738	1,277
0.66	3.28	0.04	0.40	0	0	0	0.13
0.15	0.77	0.03	0.06	0.18	3.56	1.41	0.77
16	158	36	63	40	8	0	33
360	60	40	20	50	280	200	70
377	835	3,040	4,158	4,039	4,800	3,837	2,564
241	769	3,016	4,144	4,036	4,589	3,822	2,552
7.2	4.8	6.8	4.3	5.1	6.2	4.1	4.8
8.3	3.4	3.5	4.9	4.6	5.8	8.2	4.5
19.2	4.0	7.7	11.9	89.3	87.6	44.5	26.2
3.0	0.7	1.7	1.6	2.3	32.0	26.0	6.8
5,033	1,700	2,100	1,567	900	>8,000	33	0
4,667	700	700	200	400	5,700	0	0
5,833	367	800	933	800	5,733	5,067	33
	<0.10			<0.05			<0.01
	4.84			<0.05			4.49
	0.017			0.009			<0.001
	0.060			0.012			0.019
	<0.10			<0.01			0.43
	<0.10			<0.01			<0.10
	17.57			109.74			6.30
	<0.10			<0.10			<0.10
	0.017			<0.01			0.023
	0.067			<0.01			0.023
	<0.05			<0.05			<0.01
	0.07			<0.05			0.036
	0.010			0.005			0.008
	0.026			0.009			0.013
	<0.01			<0.01			<0.01
	<0.01			<0.01			<0.01
	153.6			526.0			503.6
	<5.0			<5.0			<5.0
	83.28			3.88			182.72
	<0.10			<0.10			<0.10
	8.58			6.41			11.34
	<0.10			0.10			0.56
	<0.0003			0.0008			<0.0003
	0.010			<0.005			<0.005
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	1.51			1.08			1.68

Table 7. *Water quality data for upstream stations, Red Rock Creek,*

Variable	January	February	March	April
Temperature (°C)	1.0	0.75	11.0	16.0
pH	9.1	8.5	8.9	8.2
Hardness, total (mg/L $CaCo_3$)	358	275	453	463
Hardness, calcium (mg/L $CaCo_3$)	140	106	218	430
Alkalinity (mg/L $CaCo_3$)	320	246	348	403
Dissolved oxygen (mg/L)	13.9	10.9	9.6	10.4
Turbidity (JTU)	—	162	260	105
Conductivity (μmhos/cm)	1,379	1,766	1,586	1,611
Velocity (m/s)	—	—	—	0.08
Boron (μg/L B)	175	130	220	220
Chloride (mg/L Cl)	135	151	199	198
Nitrate (mg/L NO_3)	7.53	5.37	1.64	0.04
Ortho-Phosphate (mg/L PO_4)	1.22	0.44	0.13	0.09
Sulfate (mg/L SO_4)	92	66	210	176
Color (standard units)	0	35	40	40
Total solids (mg/L)	861	810	1,199	1,108
Dissolved solids (mg/L)	766	671	932	1,046
Oil and grease (mg/L)	2.4	1.4	0.1	2.3
Oil and grease, surface (mg/L)	2.1	4.8	1.4	4.4
COD (mg/L)	16.6	15.8	17.3	20.4
BOD_5 (mg/L)	2.9	4.5	2.2	4.6
Total coliform (100 mL)	40	133	100	267
Fecal coliform (100 mL)		100	17	33
Fecal streptococcus (100 mL)	20	250	383	67
Iron, dissolved (mg/L Fe)			<0.10	
Iron, suspended (mg/L Fe)			9.67	
Lead, dissolved (mg/L Pb)			0.011	
Lead, suspended (mg/L Pb)			0.033	
Manganese, dissolved (mg/L Mn)			<0.10	
Manganese, suspended (mg/L Mn)			0.10	
Magnesium, dissolved (mg/L Mg)			15.70	
Magnesium, suspended (mg/L Mg)			1.35	
Zinc, dissolved (mg/L Zn)			<0.01	
Zinc, suspended (mg/L Zn)			0.033	
Copper, dissolved (mg/L Cu)			<0.05	
Copper, suspended (mg/L Cu)			0.05	
Chromium, dissolved (mg/L Cr)			0.007	
Chromium, suspended (mg/L Cr)			0.041	
Silver, dissolved (mg/L Ag)			<0.01	
Silver, suspended (mg/L Ag)			0.01	
Sodium, dissolved (mg/L Na)			51.5	
Sodium, suspended (mg/L Na)			<5.0	
Calcium, dissolved (mg/L Ca)			75.22	
Calcium, suspended (mg/L Ca)			0.10	
Potassium, dissolved (mg/L K)			7.92	
Potassium, suspended (mg/L K)			1.99	
Mercury, total (mg/L Hg)			<0.0003	
Selenium, total (mg/L Se)			0.010	
Organochlorines, water (μg/L)			ND[a]	
Organochlorines, sediment (μg/L)			ND	
Organophosphates, water (μg/L)			ND	
Organophosphates, sediment (μg/L)			ND	
Chlorine, free (mg/L)			ND	
Cyanide (μg/L)			ND	
Ammonia (μg/L)			1.42	

[a] ND = Not detected..

Oklahoma, 1975 (Benham-Blair & Affiliates, Inc. 1976).

May	June	July	August	September	October	November	December
17.0	23.5	25.5	29.0	20.5	19.5	15.0	6.5
7.4	7.5	7.8	8.0	8.0	7.9	7.6	8.0
80	183	320	366	517	388	246	343
52	109	100	110	237	212	151	230
48	136	346	366	480	469	274	371
6.9	5.7	6.0	6.6	7.4	3.8	3.3	7.3
1,350	275	155	105	60	125	82	50
156	519	1,078	966	1,162	1,120	663	952
—	0.37	0.38	0.17	0	0.08	0	0
40	90	145	265	400	265	185	513
9	50	95	74	82	81	43	66
0.27	0.89	2.88	0	0	0	0.08	0.22
0.92	0.70	0.52	0.31	1.22	0.72	0.24	0.28
9	17	86	115	109	88	148	75
1,400	475	30	50	45	60	60	30
1,020	500	795	598	755	748	645	606
368	320	663	540	726	684	599	561
3.9	3.0	5.0	4.5	3.1	2.8	3.5	4.8
3.2	3.9	4.2	5.0	15.0	4.2	7.4	3.5
38.4	13.6	6.1	14.2	9.8	22.4	19.6	20.2
4.3	1.9	1.4	4.1	2.2	5.8	2.2	2.1
3,533	1,600	1,133	800	100	267	367	267
1,777	867	200	168	33	67	267	267
9,433	167	233	467	0	100	33	233
	<0.10			<0.01			0.1
	2.92			1.15			7.1
	<0.001			0.003			<0.005
	<0.001			0.008			0.013
	<0.10			<0.10			<0.05
	<0.10			<0.10			0.30
	50.92			<0.10			39.8
	<0.10			<0.10			2.1
	<0.01			<0.01			<0.01
	<0.01			0.038			0.04
	<0.05			<0.01			<0.05
	<0.05			<0.010			<0.05
	<0.001			0.005			<0.005
	0.015			0.013			0.025
	<0.01			<0.01			<0.01
	<0.01			<0.01			<0.01
	136.5			124.4			186.0
	<5.0			<5.0			<5.0
	1.12			48.96			90.6
	<0.10			<0.10			1.5
	4.74			6.10			4.7
	0.67			0.56			1.7
	<0.0003			<0.0003			<0.0005
	<0.005			<0.005			<0.005
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	1.48			1.22			1.68

Table 8. *Water quality data for downstream (perennial) station,*

Variable	January	February	March	April
Temperature (°C)	2.0	0.75	12.0	17.0
pH	8.8	8.3	8.7	8.5
Hardness, total (mg/L $CaCo_3$)	308	260	419	400
Hardness, calcium (mg/L $CaCo_3$)	230	118	152	220
Alkalinity (mg/L $CaCo_3$)	248	252	298	303
Dissolved oxygen (mg/L)	13.8	11.0	10.1	12.4
Turbidity (JTU)	—	130	152	105
Conductivity (μmhos/cm)	1,994	1,864	1,671	1,812
Velocity (m/s)	—	—	—	0.40
Flow (m^3/s)	5.66	9.20	18.41	7.79
Boron (μg/L B)	160	130	170	160
Chloride (mg/L Cl)	257	185	272	497
Nitrate (mg/L NO_3)	4.43	4.43	1.51	0.35
Ortho-Phosphate (mg/L PO_4)	0.46	0.43	0.15	1.71
Sulfate (mg/L SO_4)	130	66	165	208
Color (standard units)	10	35	40	70
Total solids (mg/L)	1,086	898	1,123	1,162
Dissolved solids (mg/L)	1,005	762	981	1,038
Oil and grease (mg/L)	1.2	4.8	0	4.0
Oil and grease, surface (mg/L)	2.1	0.7	1.2	4.5
COD (mg/L)	10.0	15.3	16.5	10.6
BOD_5 (mg/L)	3.4	2.6	2.4	5.4
Total coliform (100 mL)	120	483	933	2,200
Fecal coliform (100 mL)	30	133	350	67
Fecal streptococcus (100 mL)	20	467	483	67
Iron, dissolved (mg/L Fe)			<0.05	
Iron, suspended (mg/L Fe)			4.9	
Lead, dissolved (mg/L Pb)			<0.005	
Lead, suspended (mg/L Pb)			0.027	
Manganese, dissolved (mg/L Mn)			<0.05	
Manganese, suspended (mg/L Mn)			0.24	
Magnesium, dissolved (mg/L Mg)			37.5	
Magnesium, suspended (mg/L Mg)			1.0	
Zinc, dissolved (mg/L Zn)			<0.01	
Zinc, suspended (mg/L Zn)			0.04	
Copper, dissolved (mg/L Cu)			<0.05	
Copper, suspended (mg/L Cu)			<0.05	
Chromium, dissolved (mg/L Cr)			<0.005	
Chromium, suspended (mg/L Cr)			0.021	
Silver, dissolved (mg/L Ag)			<0.01	
Silver, suspended (mg/L Ag)			<0.01	
Sodium, dissolved (mg/L Na)			224.3	
Sodium, suspended (mg/L Na)			<5.0	
Calcium, dissolved (mg/L Ca)			88.5	
Calcium, suspended (mg/L Ca)			0.4	
Potassium, dissolved (mg/L K)			5.0	
Potassium, suspended (mg/L K)			1.0	
Mercury, total (mg/L Hg)			<0.0005	
Selenium, total (mg/L Se)			<0.005	
Organochlorines, water (μg/L)			1.3 chlordane	
Organochlorines, sediment (μg/L)			ND[a]	
Organophosphates, water (μg/L)			ND	
Organophosphates, sediment (μg/L)			ND	
Chlorine, free (mg/L)			ND	
Cyanide (μg/L)			ND	
Ammonia (μg/L)			1.59	

[a] ND = Not detected.

Red Rock Creek, Oklahoma, 1975 (Benham-Blair & Affiliates, Inc. 1976).

May	June	July	August	September	October	November	December
17.0	23.0	25.0	26.0	17.5	20.0	12.5	6.0
6.9	7.5	8.3	8.2	8.2	8.2	8.6	8.3
90	149	309	380	460	344	332	366
55	102	73	119	248	222	232	208
46	92	232	262	220	218	219	225
7.0	5.7	6.6	6.4	10.4	5.6	9.6	10.7
1,425	1,200	120	85	130	110	70	175
166	496	1,320	1,784	1,505	1,920	1,640	2,145
—	0.66	0.33	0.25	0.18	0.11	0.19	0.19
59.46	44.97	6.06	2.26	1.50	0.62	1.13	1.17
50	50	175	210	230	175	185	220
9	74	222	358	282	405	335	465
0.04	0	0	0	0	0	2.53	5.09
0.77	1.53	0.55	0.41	3.00	0.57	0.99	1.29
8	5	89	192	180	155	178	174
1,280	150	35	57	50	60	50	10
1,143	1,766	937	1,068	999	1,155	1,024	1,328
203	302	793	992	894	1,083	960	1,186
4.3	2.1	5.0	4.3	2.6	4.7	4.2	4.8
2.6	3.3	3.9	6.9	4.7	6.0	7.1	3.9
43.6	48.6	12.8	20.9	14.2	22.4	21.7	17.6
4.6	2.4	4.9	6.3	5.2	13.5	7.8	2.8
1,600	1,467	533	567	1,633	133	367	7,267
1,833	467	133	100	167	67	267	1,500
8,300	633	100	200	67	267	33	567
	<0.10			<0.01			<0.01
	28.22			2.64			5.82
	0.027			<0.001			<0.001
	0.058			0.002			<0.001
	<0.10			<0.01			<0.10
	1.18			<0.01			<0.10
	8.84			49.12			<0.10
	12.58			<0.10			<0.10
	0.067			<0.01			<0.01
	0.192			<0.01			0.038
	0.05			<0.05			<0.01
	0.07			<0.05			0.036
	0.006			0.010			0.007
	0.077			0.019			0.022
	<0.01			<0.01			<0.01
	<0.01			<0.01			<0.01
	58.9			128.0			385.1
	<5.0			<5.0			<5.0
	56.01			0.98			38.11
	3.95			<0.10			<0.10
	7.14			4.74			8.72
	8.45			0.67			1.29
	<0.0003			<0.0003			<0.0003
	<0.005			<0.005			<0.005
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	ND			ND			ND
	2.23			1.94			2.52

Table 9. *Physicochemical characteristics of three intermittent (1–3) and five perennial (4–8) headwater streams on the eastern side of the Coteau de Prairies, South Dakota (McCoy and Hales 1974). Measurements were made in May 1973 when flow was present in all streams.*

	Stream type							
	Intermittent			Perennial				
Physicochemical variable	1	2	3	4	5	6	7	8
Conductivity (μmhos)	1,290	1,490	1,850	—	725	960	1,300	840
pH	8.0	8.1	8.0	8.7	8.8	8.2	8.3	—
Turbidity (JTU)	5	4	6	1	25	23	5	15
Total hardness (mg/L as $CaCo_3$)	670	800	960	630	370	480	660	325
Calcium hardness (mg/L as $CaCo_3$)	390	490	580	400	250	290	390	265
Total alkalinity (mg/L as $CaCo_3$)	310	260	260	290	250	290	320	285
Sodium(mg/L)	18	28	33	37	7	16	21	—
Potassium(mg/L)	10	8	9	8	6	6	11	—
Sulfates (mg/L as SO_4)	425	460	450	275	100	320	437	220
Nitrates (mg/L as NO_3)	6.2	2.7	8.5	0.9	3.0	3.5	1.4	1.3

Table 10. *Means and ranges of physicochemical conditions by stream order in the Plum Creek drainage basin, a 5th-order intermittent stream in southeastern Texas (Whiteside and McNatt 1972).*

	Stream order				
Physicochemical variable	1	2	3	4	5
pH	7.3	7.3	7.3	7.3	7.3
	7.0–7.5	6.5–7.4	6.9–7.4	7.2–7.4	7.2–7.4
Total alkalinity (mg/L)	205	176	174	198	210
	110.0–327	73.0–250	90.0–443	124.0–367	176.0–238
Dissolved oxygen (mg/L)	9.9	9.3	9.1	9.0	8.1
	2.8–13.1	3.2–14.5	3.5–13.2	7.9–10.0	7.0–8.7
Turbidity (JTU)	82	60	87	105	39
	8.0–268	8.0–131	21.0–377	41.0–329	20.0–97
Conductivity (μmhos/cm)	520	731	740	1,054	883
	133.0–2,000	110.0–1,900	190.0–1,833	248.0–1,843	530.0–1,400
Discharge (cm)	0.01	0.02	0.03	0.37	0.41

Table 11. *Ranges of physicochemical conditions at a permanent pool on intermittent Aquilla Creek, Texas, March–December 1980 (Campbell and Clark 1982).*

Physicochemical Variable	Range of values
Temperature (°C)	11–29
pH	7.4–7.6
Dissolved oxygen (mg/L)	0.7–6.7
Conductivity (μmhos/cm)	300–1500
Current velocity (cm/s)	0
Total filterable hydrolyzable phosphate phosphorous (mg/L PO_4–P)	0.00–0.70
Nitrate nitrogen (mg/L NO_3–N)	0.01–0.90
Nitrite nitrogen (mg/L NO_2–N)	0.00–0.01
Ammonia nitrogen (mg/L NH_3–N)	0.03–0.10
Chlorophyll *a* (mg/m^3)	3.42–32.1

luted reach, whereas they were 3.4 and 3.8 g O_2/m^2/day, respectively, in a polluted reach. Differences in gross primary production between reaches were attributed to partial scouring and burial of benthic algae in the polluted reach (effluents resulted in heavy sedimentation) and presence of toxic metal ions. [Production exceeded respiration in the unpolluted reach, indicating that the stream was autotrophic.]

Busch and Fisher (1981) measured rates of production and respiration during summer in an intermittent desert stream in Arizona. Two types of benthos were present in the stream: (1) mats of the filamentous green alga *Cladophora glomerata* and associated epiphytes and (2) assemblages of attached diatoms and blue-green algae. The stream was determined to be autotrophic ($P \div R = 1.7$); gross photosynthesis was 8.5 g O_2/m^2/day and community respiration was 5.1 g O_2/m^2/day.

Israel

The rate of breakdown of leaf litter of the common reed *Phragmites australis* and the exotic eucalyptus *Eucalyptus rostrata* were compared in one perennial and three ephemeral streams in Israel by Herbst and Reice (1982). Two of the ephemeral streams flowed throughout the 10-week study; the other ceased flow for a 2-week period midway through the study. Breakdown of leaf litter in the latter halted completely during the dry phase. After resumption of flow, breakdown proceeded at a rate similar to that measured before cessation of flow. Alternate wetting and drying did not enhance breakdown. Cessation of breakdown was attributed to the absence of shredding macroinvertebrates during the dry period. [An alternate explanation is reduced microbial colonization and activity in the absence of water.]

Kansas

Gurtz et al. (1982) documented import, storage, decomposition, and export of organic matter in a pristine stream on the Konza Prairie Research Natural Area in Kansas. Upper reaches (1st- and 2nd-order) were ephemeral and drained watersheds vegetated by grasses (big bluestem, *Andropogon gerardi*; little bluestem, *Schizachyrium scoparium*; and Indiangrass, *Sorghastrum nutans*). Lower intermittent reaches flowed through riparian gallery forest (chinkapin oak, *Quercus muehlenbergii*; bur oak, *Q. macrocarpa*; hackberry, *Celtis occidentalis*; elm, *Ulmus* spp.; and green ash, *Fraxinus pennsylvanica*). The upper area received only 28% as much allochthonous input (mostly grass, spread out through the year) as did the lower area (primarily during autumn leaf fall), but retained a larger fraction of it. Total annual organic inputs were 135.8 g/m^2 in the upland and 475.5 g/m^2 in the lower reaches. Lower reaches exported more organic matter during storm flows, thereby reducing *in situ* decomposition. Decomposition proceeded at similar or slightly lower rates than reported for other streams. The degree of decomposition was related to retentiveness of the channel; dry, upstream channels were retentive with slow decomposition. Decomposition rates were higher in lower reaches because of the presence of water, but were vulnerable to disruption by storm flow; that is, materials were exported before completing decomposition. Concentrations of all size categories of organic matter increased during storm flows. These exports represented pulses of organic matter loading downstream. The authors recommended that natural retention structures (debris dams) in the headwaters should not be removed by clearing and snagging or channelization, thus maximizing the decomposition of organic matter by native biota and enhancing downstream water quality. They also suggested that consideration be given to the design of artificial structures for enhancing retention of stored organic matter.

Smith (1982) experimentally manipulated densities of macroinvertebrates in an intermittent, tallgrass-prairie stream in Kansas to determine their effect on decomposition rates of leaf litter. No significant effect was observed, suggesting that decomposition in prairie headwaters is dominated by microbial, fungal, and physical factors.

Killingbeck (1984) measured leaf litter accumulation in an ephemeral prairie stream in Kansas. At the sampling station, the stream was bordered by a gallery forest consisting of hackberry, bur oak, and slippery elm (*Ulmus rubra*). Accumulation of litter in the streambed was 468 g/m^2/year. All the litter consisted of leaves from the gallery forest. None was derived from prairie grasses dominating riparian zones in upper areas of the watershed, which suggested complete decomposition in the headwaters.

Ontario

Comparison of drift of solid organic matter in adjacent intermittent and perennial streams in southern Ontario was attempted by Dance et al. (1979). However, samplers in the intermittent stream were swept away during spring flooding when particulate drift was high. Nevertheless, data on dissolved nutrient transport indicated that solid drift was insignificant in the intermittent stream, perhaps because decomposition was advanced compared to the perennial stream, due to retentiveness of isolated pools.

Southeast

Similar breakdown-rate comparisons were reported by Blood et al. (1986) for red maple (*Acer rubrum*) and Carolina ash (*Fraxinus caroliniana*) in southeastern

coastal-plain blackwater streams. Leaf litter of both species exhibited a 50% weight loss after 6 months in intermittent and 2 months in perennial streams. Blood et al. (1986) concluded that litter processing in streams was regulated largely by stream-flow characteristics; lack of constant inundation decreased the period in which processing could occur and also decreased the abundance of shredding macroinvertebrates.

Texas

Hill et al. (1986) measured breakdown rates of pecan (*Carya illinoiensis*), box elder (*Acer negundo*), and Shumard oak (*Quercus shumardii*) leaves placed in polypropylene mesh bags in 3 perennial and 3 intermittent stream sites in Texas for 24 weeks following leaf fall. Significant downstream increases in breakdown rates were observed for pecan in the perennial and intermittent streams and for red oak in perennial streams. Breakdown of pecan and red oak proceeded more rapidly in perennial streams. Streams did not differ significantly in the breakdown of box elder leaves, which were more resistant to breakdown than those of the other species.

Measurements of benthic metabolism by Hill and Gardner (1986) in one intermittent and one perennial Texas prairie stream suggested that rigorous and unpredictable conditions within intermittent streams may be more conducive to primary producers than to heterotrophic organisms. Net primary production and respiration of stream substrates were measured monthly as changes in O_2 concentration within sealed chambers. Production in the perennial stream varied from 2.6 to 439.2 mg $O_2/m^2/h$ (mean = 119.2 mg $O_2/m^2/h$). In the intermittent stream, production varied from 3.2 to 370.4 mg $O_2/m^2/h$ (mean = 117.9 mg $O_2/m^2/h$). Rate of production was not significantly different between the two streams. Respiration varied from 7.2 to 311.2 mg $O_2/m^2/h$ (mean = 83.9 mg $O_2/m^2/h$) in the perennial stream and from 7.1 to 133.6 mg $O_2/m^2/h$ (mean = 45.6 mg $O_2/m^2/h$) in the intermittent stream. Respiration in the intermittent stream was significantly lower than in the perennial stream. [Production exceeded respiration in the intermittent stream, indicating that it was autotrophic.]

Plants

Summary

The flora of intermittent streams is largely inconspicuous and thus has been poorly studied. Vascular macrophytes are essentially absent from intermittent streams, and macroscopic algae (e.g., *Chara*) are rare. Rigors of desiccation, high turbidities, unstable substrates, or periodically high water velocities may be responsible for the paucity of submerged macrophytes. Conversely, emergent aquatic vegetation is common and abundant along many intermittent streams, especially along the banks of permanent pools, but specific investigations regarding vegetation ecology in intermittent streams have not been conducted. Assemblages of emergents along intermittent streams are probably similar in composition and function to those bordering perennial streams, but perhaps are somewhat less diverse and have lower annual productivity. However, these deficits are probably compensated for by invasive terrestrial vegetation; ephemeral stream beds often support terrestrial vegetation during dry seasons.

Phytoplankton is generally less diverse and abundant in streams and rivers than in lentic (standing water) habitats because many species lack resistance to damage incurred by turbulence, and turbidity decreases light level (Hynes 1970). Nevertheless, phytoplankton is an important source of primary production in flowing waters. Though empirical evidence is sparse, structure and function of phytoplankton assemblages in intermittent streams during periods of low flow are probably similar to those in perennial streams. However, during periods of no flow, phytoplankton assemblages in isolated pools of intermittent streams may achieve high species richness and production. No studies have been made of temporary assemblages, but the similarity of these habitats to small standing pools suggests conditions (low turbidity, lack of turbulence) that are highly suitable to many phytoplankters. The presence of phytoplanktivorous zooplankton atypical of lotic (flowing) waters in these pools provides supporting evidence for this conclusion.

Intermittent streams are inhabited by a diverse array of diatoms and other periphytic (attached) algae. Periphyton are the most important primary producers in intermittent streams and, along with allochthonous inputs of leaf litter, compose the trophic base of these systems. No information exists on the relative importance of these sources in intermittent streams, but detrital material requires microbial processing before it can be assimilated by most organisms; periphyton is directly assimilable. Microbial processing results in a significant energy loss. Accordingly, relatively small amounts of periphyton can result in secondary production equal to that resulting from much larger inputs of detritus. Despite low standing biomass, primary production of periphyton can be appreciable because turnover rates are high. In addition to its trophic value, periphyton also provides cover for a diverse array of invertebrates; carnivorous fish can often be observed eating invertebrates in thick algal growths on rocks and boulders in intermittent streams. Periphytic algae are also excellent indicator organisms for overall quality of the stream ecosystem.

Reference Annotations

Phytoplankton

Mahnken and Wilhm (1982) collected phytoplankton from Otter Creek, an intermittent stream in north-central Oklahoma. Sampling was conducted over four 24-h periods in June 1976 and June–August 1977. Ninety-four taxa were collected; most were planktonic diatoms, green algae, and euglenophytes. Mean phytoplankton densities varied from 913 to 12,545 cells per milliliter, well within ranges reported in the literature for perennial streams. Chlorophyll *a* values varied from 1 to 55 mg/m^3, also within ranges reported in the literature for perennial streams. Pheophytin *a*, a degradation product of chlorophyll *a* indicative of phytoplankton populations that are old or in poor condition, was present in high concentrations on only one date. Chlorophyll concentrations and phytoplankton densities increased in the morning and reached maxima in late morning or in the afternoon. Increases were apparently due to rapid production. Natural mortality and increased grazing by zooplankton probably caused decreases in late afternoon and in the evening. The range in species diversity of Otter Creek phytoplankton was indicative of moderate to slight pollution (Staub et al. 1970), probably caused by runoff from pastureland and cattle feedlots. Values of the algal pollution index (Palmer 1969) for daylight samples indicated evidence of high organic pollution, but values for samples taken at night were below this threshold. Diel variation was a result of daytime recruitment of indicator species, not diurnal changes in water quality.

Periphyton

Seyfer and Wilhm (1977) collected periphyton during winter, spring, and summer from 3rd- through 6th-order sites on Otter Creek, an intermittent prairie stream in north-central Oklahoma. Eighty-five taxa of periphyton were collected; 78 were diatoms. Winter, spring, and summer collections included 52, 56, and 69 taxa, respectively. The total number of taxa and species diversity increased with stream order, but taxa other than diatoms decreased. Many pollution-tolerant algae were collected. Chlorophyll *a* and ash-free weight values decreased with increased order. These trends suggested mild nutrient enrichment, probably from pastureland and cattle feedlots in the headwaters.

Wilhm et al. (1978a) conducted an investigation of the periphyton assemblages in two intermittent streams (Greasy and Red Rock creeks) in north-central Oklahoma. Mean width and depth were about 4 and 1 m, respectively, at sampling locations on Greasy Creek, and 6 and 2 m on Red Rock Creek; substrates were primarily silt. Seventy-one taxa were collected in Greasy Creek and 61 taxa were collected in Red Rock Creek. The most commonly occurring species in the creeks were *Gomphonema olivaceum* and species belonging to the genera *Navicula* and *Nitzschia*. Contrary to the general longitudinal trend for most organisms in streams, more taxa and higher species diversities were present at upstream stations; however, total densities were higher at downstream sites. More shading and higher current velocities at the lower stations may have reduced colonization of some species. Species richness in the intermittent streams was higher than in the Arkansas River and in Skeleton Creek, a nearby perennial stream polluted with domestic and oil-refinery effluents, but lower than in a clear, spring-fed stream.

Benthos

Sessile, filter-feeding ciliates were collected from a variety of streams, including intermittent streams, of southern Ontario (Taylor 1983). Abundances in intermittent streams were comparable to those in other stream types; ciliate abundance was high following resumption of flow. Species with rigid, noncontractile stalks were more common in intermittent streams than in streams with stable flows, apparently because these forms were better able to withstand the high water velocities present during sudden, violent rain storms.

Invertebrates

Summary

Macroinvertebrates dominate intermittent streams numerically and functionally. Virtually all biological processes of intermittent streams involve or are mediated by macroinvertebrates. They consume algae, process and ingest allochthonous litter, affect concentrations of dissolved gases and nutrients, feed on each other, and are trophically linked to vertebrates as predators and prey. In some instances, their activities may even alter the geomorphology of a stream (e.g., crayfish [Crustacea: Astacidae] burrows). In addition, they are useful indicators of perturbations.

A wide variety of macroinvertebrates inhabit intermittent streams. Insects (especially aquatic larvae of terrestrial adults), crustaceans (noninsect aquatic arthropods), annelids (segmented aquatic earthworms and leeches), and molluscs (snails, fingernail clams, and freshwater mussels) compose the most species and individuals in intermittent streams. Many terrestrial insects, especially beetles (Coleoptera) and true bugs (Heteroptera), are common along shores of intermittent streams and readily invade the stream channel as it dries. Terrestrial insects also enter intermittent streams by falling from the overlying riparian canopy. As indicated by the following reference annotations, a wide diversity of invertebrates reside in intermittent streams. We did not attempt to compile species lists.

Diversity, species richness, and density of invertebrates tends to increase in intermittent streams from the headwaters downstream with increases in habitat complexity, stream size, and permanence of flow. Analagous differences in these variables occur seasonally; values are highest when flows are high and a variety of habitat types are wet. For example, obligate riffle-dwelling species are present only during periods of flow.

Few species are restricted to intermittent streams, but several taxa that are absent from perennial streams are present in intermittent systems. For example, clam shrimps (Conchostraca) and fairy shrimps (Anostraca) require seasonal drying for completion of life cycles. Primarily found in vernal pools, these shrimp also live in many intermittent streams. Similarly, many species of crustacean zooplankton normally found in ponds and lakes are rare in flowing streams, but they become established in pools of intermittent streams following cessation of flow. Some species present in intermittent and perennial streams reach much higher densities in the former, perhaps as a result of decreased predation or competitive pressures. Nevertheless, macroinvertebrate assemblages are depauperate and instable in intermittent streams compared with perennial streams because many species are intolerant of the physicochemical extremes of intermittent streams or are unable to withstand desiccation (or lack a strategy for coping with desiccation). Accordingly, bi- or multi-voltine species (two or more generations per season), species with life cycles of 2 years or more, and lotic species with a major growth period in summer followed by emergence in fall are generally absent from intermittent streams.

Invertebrate assemblages reestablish rapidly in intermittent streams following drought, provided they have opportunities or adaptations for surviving dry periods. Various means are used by invertebrates to cope with summer drought. Some species emigrate to nearby perennial waters or emerge before cessation of flow and survive summer drought as aerial or terrestrial adults. Others survive in permanent pools, in damp areas under rocks or leaf litter, or burrow into the substrate. Accordingly, permanent pools, riparian vegetation, and low silt loads (silt fills interstitial spaces in the substrate) are vital to the survival of many invertebrates residing in intermittent streams.

Drift of invertebrates is common in perennial streams and redistributes organisms throughout a stream, thereby allowing colonization of available habitats. Drift also makes these organisms more available to predators, especially fish, and therefore affects secondary production of streams and receiving systems significantly. The significance of drift in intermittent streams is unclear. Some species that are common in intermittent streams exhibit little or no propensity for drifting, perhaps as an adaptation to maintaining position during floods. Nevertheless, high water velocities displace many invertebrates downstream in intermittent streams, and lentic assemblages are quickly swept away upon resumption of flow. Drift in intermittent streams is therefore less regular than in perennial streams, but seems to be comparable in magnitude over time.

Reference Annotations

Alberta

Invertebrate drift was sampled by Clifford (1972) in an intermittent stream draining marshlands in Alberta. Most drift consisted of organisms originating in the marsh. Blackfly (Simuliidae) larvae and certain midges (Chironomidae) were the only abundant lotic taxa collected, but planktonic rotifers (Rotatoria) and immature copepods (nauplii) from the marsh were numerically dominant throughout most of the study. Drift (including blackflies and midges) in the intermittent tributary was greater during daytime than at night, contrary to the periodicity observed in the perennial main stream. Drift from the intermittent stream was considered to contribute a significant number of animals to the main stream.

A diverse and abundant crustacean assemblage was documented in an intermittent prairie stream in east-central Alberta (Retallack and Clifford 1980). Sixty species were collected: Anostraca (6 species), Conchostraca (3), Notostraca (1 tadpole shrimp), Cladocera (26), Ostracoda (9), Copepoda (13), and Amphipoda (2). Other abundant invertebrate taxa included rotifers, dragonflies, true bugs, beetles, caddisflies, and snails. Brook sticklebacks and fathead minnows were common. The crustacean assemblage was much richer than normally associated with a lotic system. This richness was attributed to the intermittency of the stream; a dry phase is required for successful maintenance of anostracan and conchostracan populations. [These findings emphasize that intermittent streams are distinctive habitats possessing unique attributes critical to the survival of specialized species.]

Arizona

Lewis and Burraychak (1979) documented effects of effluents from open-pit copper mines on the biota of an intermittent stream in central Arizona. Of 43 invertebrate taxa in intermittent reaches, only 6 were found below the confluence of mine discharge channels. The difference was attributed to reduced primary production, substrate compaction, and elimination of permanent pools by sedimentation. Surface dwelling and migratory species were dominant below the outfalls.

Species richness was significantly correlated with surface area of isolated pools in an intermittent stream in northern Arizona (Stout 1982). Species lists were not presented. In the smaller pools, densities were higher, but most of the individuals were mosquito larvae. Predatory beetles were absent from these small pools and emigrated when introduced, apparently because of high temperatures and homogeneous substrates.

Australia

Towns (1985) sampled benthic invertebrates in Brown Hill Creek, near Adelaide, South Australia. The stream typically did not flow for about 6 months annually, from about December through May. The bulk of the fauna consisted of stoneflies, midges, long-horned caddisflies (Leptoceridae), and dytiscid beetles. Other invertebrates present were copepods, ostracods, amphipods, tubifex worms (Annelida: Tubificidae), true bugs, mosquitoes, mayflies, various beetles, and caddisflies. Most species were present only during winter, appearing soon after flow commenced, and were most abundant in moderate to fast currents (0.10 m/s). As a result, density was higher, and maximum species richness occurred sooner in riffles than in pools. Highest species richness and density in the pools occurred in late December, immediately before cessation of flow. The larvae of only two species of fully aquatic insects, the long-horned caddisflies *Leptorussa darlingtoni* and *Lectrides varians*, remained in permanent pools once flow ceased. A distinctive feature of the insect fauna was the tendency for more common species to have extremely unusual life histories or methods of reproduction, some of which were clearly adaptations to the intermittent environment. These included terrestrial egg deposition, rapid larval growth at low temperatures, and advanced ovoviviparity. Recruitment in many species was assumed to be through flying adults immigrating from perennial reaches. The only vertebrate present in the stream was the leptodactylid frog *Pseudophryne bibroni*; tadpoles were most abundant in pools, where they appeared as soon as the stream commenced flowing and remained throughout the winter. Tailed froglets appeared immediately before cessation of flow; none remained in permanent pools during summer.

California

Abundances and habitat associations of mosquito larvae in an intermittent California stream were monitored by Abell (1959). Larvae were restricted to isolated, lateral pools during flow. During summer drought, high abundances were found in small, temporary pools free of algae and predators (e.g., beetles and fish), but desiccation eventually destroyed these populations. Few larvae lived in larger, deeper permanent pools that were inhabited by predators. Resumption of flow resulted in export of larvae to downstream areas.

Indiana

Clifford (1966) assessed seasonal structure of macroinvertebrate assemblages in an ephemeral Indiana stream. The surface of the streambed was completely dry for 38 days in late summer and early fall. The stream fauna was dominated by two crustaceans, the scud *Crangonyx forbesi* (Amphipoda) and the aquatic sow bug *Lirceus fontinalis* (Isopoda), which occurred in substantial numbers throughout the year. These crustaceans consistently composed 80%–90% of total numbers except in spring when other organisms flourished. They survived the dry season as juveniles in deep subsurface seepage and humid interstitial spaces. Both crustaceans had annual life cycles. Adult *Crangonyx* reproduced and died during spring, but *Lirceus* continued to reproduce into summer until stopped by desiccation. Individuals of the new generations of both grew little during the dry summer and fall, but grew quickly in late fall and winter following resumption of flow. Other aquatic organisms were divided into a late-summer–fall assemblage, characteristic of the stream when it was dry or nearly so, and a late-winter–spring assemblage present during flow. The summer–fall assemblage consisted of aquatic beetles and the horsehair worm *Gordius* which burrowed into the substrate; short life-cycle mosquitoes; and water boatmen (Hemiptera, Corixidae), which emigrated following desiccation of the stream. The winter–spring assemblage consisted primarily of five caddisflies, three stoneflies, and two mayflies. Caddisflies survived dry periods as large aestivating larvae or pupae in leaf litter, and stoneflies and mayflies survived either as tiny nymphs in the substrate or as eggs. All were univoltine. Ephemerality was considered responsible for the absence of bivoltine or multivoltine species (species with life cycles of 2 years or more) and species with a major growth period in summer and an emergence in fall. Moist interstitial spaces in the substrate were critical to the survival of many species; these were inhabited during the dry season, allowed seepage, and reduced catastrophic drift by reducing water velocities during floods. Presence of interstitial spaces was attributed to local geology and the almost nonexistent silt load; the latter was a product of extensive riparian woodlands.

Kansas

The Kansas Department of Health and Environment (1981) studied the effects of floodwater-retarding impoundments on the biota (including macroinvertebrates) of intermittent streams in Kansas. Curtailed

funding precluded a comprehensive and detailed analysis of the data, but preliminary analyses suggested that macroinvertebrate richnesses were lower and densities higher below impoundments than in control streams.

Gurtz (1986) monitored invertebrate communities for 10 months in perennial and intermittent tallgrass-prairie streams at Konza Prairie, Kansas. Species richness was lowest at the site with fewest total days flow and highest in the perennial reach. Several taxa were essentially restricted to the perennial reach; these had longer generation times than similar taxa in the intermittent stream or lacked strategies for resisting drought. Hydrologic characteristics influencing the invertebrate communities included suitable flow conditions both at sampling sites and in upstream reaches, proximity of the nearest permanent pool, durations of dry periods, and vertical extent of drying in the channel bed.

Past and recent (1983–84) assemblages of fishes and selected aquatic macroinvertebrates in Big Creek, an intermittent stream in western Kansas, were compared by Eberle et al. (1986). The stream was impounded by a number of dams and low-water bridges, and agricultural runoff increased turbidity and siltation in the creek. Fish kills were common in pools as a result of low dissolved oxygen concentrations. Recent collections included one species of crayfish (*Orconectes virilis*), three freshwater unionid mussels (*Anodonta grandis*, *Proptera laevissima*, and *Quadrula quadrula*), and one species of fingernail clam (*Musculium transversum*). Two crayfishes, four mussels, and one species of clam reported in earlier collections (dating back to 1870) were not collected.

Hudson (1986) reviewed information on the midges that often dominate the fauna of intermittent streams. These species possess either a tolerance for drought or the ability to colonize rapidly seasonally dry stream reaches following droughts. Larvae of *Hydrobaenus*, *Paratanytarsus*, *Tanytarsus*, *Tribelos*, *Phaenopsectra*, *Polypedilum*, and *Wirthiella* avoid desiccation by aestivation in cocoons. Larvae leave cocoons on resumption of flow, grow to adulthood, and oviposit; offspring continue the cycle by constructing cocoons. Midges, which typically are found in permanent bodies of water but emerge early in spring (e.g., *Micropsectra*, *Chironomus*, *Sergentia*, *Orthocladius*, *Parakiefferiella*, and *Cricotopus*), also are capable of colonizing intermittent streams. Success of a species in completing a life cycle in an intermittent habitat depends largely on its ability to grow at cool temperatures and its relative tolerance of wet and dry cycles. Larvae of some of these are capable of burrowing deep into the sediment to avoid desiccation. Because of the paucity of microbially colonized detritus in intermittent streams, midges that are capable of feeding on periphytic algae are presumably more successful and abundant in these habitats.

In Kansas, midges numbered 38 species in perennial streams, 31 in intermittent streams, and 13 in ephemeral streams (Kavanaugh and Ferrington 1986). Intermittent sites had two or three dominant species, whereas only a single species, *Euorthocladius abiskoensis*, was dominant at ephemeral sites. Highest similarities in species composition occurred between sites most similar in flow, water depth, and temperature.

New York

Movement patterns of benthic invertebrates in perennial and intermittent streams in New York were compared by Delucchi (1986). Invertebrate drift in intermittent streams was less than in perennial streams, but within-substrate movement, both up and downstream, was inferred to be important in intermittent streams.

Ohio

Stehr and Branson (1938) examined assemblage dynamics of macroinvertebrates in an intermittent Ohio stream. Insects composed the largest number (27) of aquatic taxa present; other groups included crustaceans (5), molluscs (2), annelids (2), flatworms (2 Turbellaria), and gordiid horsehair worms (2 Nematomorpha). In addition to aquatic forms, some shore species were intimately associated with the stream—for example, pygmy grasshoppers (Tetrigidae), tiger beetles (Cicindelidae), ground beetles (Carabidae), rove beetles (Staphylinidae), toad bugs (Gelastocoridae), and jumping ground bugs (Dipsocoridae and Schizopteridae). Predatory shore species preyed on emerging adults of aquatic forms and scavenged the streambed during drought. Species richness of aquatic forms was highest in summer, but densities peaked in fall. Mean seasonal densities were: spring, 180.65/m^2; summer, 38.78/m^2; fall, 776.69/m^2; and winter, 12.15/m^2. Forms requiring cool, highly oxygenated water (the small mayfly *Caenis* [Baetidae], net-spinning caddisflies [Hydropsychidae], midges, and blackflies) were present during spring, before metamorphosis in May or June. Other taxa generally increased in abundance during spring. Floods often reduced abundances severely; strong currents swept many invertebrates into the receiving stream. Abundances began to increase as soon as flows returned to normal. During summer, tolerant forms (water boatmen, broad-shouldered water striders [Heteroptera: Veliidae], water striders [Heteroptera: Gerridae], predaceous diving beetles [Dytiscidae], water scavenger beetles [Hydrophilidae], and mosquitoes) increased in abundance. Crustaceans, molluscs, annelids, horsehair worms, and flatworms burrowed deep into the substrate to avoid desiccation. Seed shrimps (Ostracoda: Cypridae), small winter stoneflies (Capniidae), and especially the annelid *Limnodrilus* increased greatly in abundance in fall. Winter stoneflies were dominant in

winter. Taxa segregated by habitat type, such as rocky riffles, sandy riffles, rocky pools, or sandy pools.

Oklahoma

Momot (1966) examined movement patterns of the crayfish *Orconectes nais* in an intermittent stream in southern Oklahoma during a 7-week period in June and July encompassing the cessation of flow. Mean density of crayfish in the stream was about 5.4 individuals per square meter. Maximum life span was 2 years; young of the year composed 96% of organisms collected in late July. The general pattern of migration was upstream and was surmised to be a redistribution mechanism that compensated for downstream movements during torrential floods; catastrophic drift during floods may transport crayfish to downstream areas occupied by predatory fishes. Upstream movements ended following cessation of flow. Intense predation by raccoons (*Procyon lotor*) was evident in the isolated pools.

The relation between stream order and macroinvertebrate diversity was examined by Harrel and Dorris (1968) in the Otter Creek drainage basin of north-central Oklahoma. The basin was a 6th-order, intermittent prairie system. One hundred eleven species of benthic macroinvertebrates were collected. Oligochaetes (9 species, 70%) and flies (46 species, 22%) composed 92% of the total pool fauna. The oligochaete *Limnodrilus* made up 66% and midge larvae (24 species) composed 19% of total numbers. Other Oligochaeta (8 species), leeches (3 Hirudinea), mayflies (5), beetles (12), biting midges (4 Diptera: Ceratopogonidae), and Mollusca (6) each formed more than 1% of total numbers. Species richness increased from 75 in 3rd-order pools to 86 in 5th-order pools. Only 68 species were collected from 6th-order pools. The decrease was attributed to heavy siltation in the lower reaches caused by backed-up waters from the receiving stream during floods. Seasonal variations in species richness and densities were evident. Annual total species richness and diversity increased from 3rd- to 5th-order streams, then decreased in the 6th-order stream. Maximum number of species and densities were found in spring following several months of continuous flow. Minimum densities were during fall following heavy rains. Highest densities were at 4th-order sites throughout the year. Lowest densities were recorded in a 6th-order reach during fall, winter, and spring (periods of flow) and at 3rd-order sites during summer drought. Greatest annual variation in species richness was in 3rd- and 4th-order streams, with the least variation in the 6th-order stream. During summer and fall, species richness was highest in 5th-order streams. During winter, species richness was similar in all stream orders. During summer, as the water level receded, midge larvae, mainly predatory species, replaced *Limnodrilus* as the dominant organism. Midge larvae increased from 13% ($158/m^2$) of the total pool fauna in June, when much of the stream was running, to 48% ($1,049/m^2$) in August, when small stagnant pools were common. *Limnodrilus* decreased from 65% ($820/m^2$) in June to 15% ($358/m^2$) in August. Between the August and September collections, more than 16 cm of rain fell, which caused flooding and scouring of the stream bed. Total densities decreased from $2,470/m^2$ in August to $565/m^2$ in September; concurrently, *Limnodrilus* increased to 59% ($334/m^2$) and midges declined to 8% ($47/m^2$). Seepage of oil-field brines in two reaches of the system decreased turbidities locally, allowing high algal production. Accordingly, densities and diversities of macroinvertebrates were enhanced. Highest densities of the midge *Polypedilum illinoense*, which is considered an indicator species of unpolluted conditions, at the stations receiving oil-field brines suggested that limited seepage of these effluents may not negatively affect stream biota.

Mathis and Dorris (1968) examined benthic macroinvertebrate assemblages in Black Bear Creek, an intermittent stream in north-central Oklahoma that received oil-field brines. Seventy-nine species were collected. Most were insects (Diptera, Coleoptera, Ephemeroptera, Trichoptera, Odonata, and Neuroptera [spongilla flies]), but the fingernail clam *Sphaerium transversum* (Mollusca: Sphaeriidae) and two species of annelids also were taken. Most individuals collected were flies and caddisflies. Above the outfall, 47 species were collected. Only 31 were taken directly below the outfall, and 55 species occurred 80 km below the effluent discharge. Abundances were extremely low below the outfall compared to upstream and downstream stations. Although oil-field brines were clearly deleterious to the benthic fauna of Black Bear Creek, effects were much less severe than in similar streams receiving domestic and oil-refinery effluents.

Wilhm et al. (1978b) described seasonal and spatial variation of benthic macroinvertebrates collected on artificial-substrate samplers in two intermittent streams of north-central Oklahoma (Greasy and Red Rock creeks). Each stream had two stations (upstream and downstream). Sixty-two taxa were collected in Greasy Creek and 64 taxa in Red Rock Creek. Two-thirds of these belonged to the orders Diptera (43 taxa), Ephemeroptera (13), and Trichoptera (9). Seasonal variation in species richness within streams exceeded differences between the streams. Several mayflies and midges were occasionally numerous in Greasy Creek. *Caenis* (a mayfly) was abundant at the upstream station from late spring through early fall; in late spring *Stenonema frontale* (a mayfly) and *Hyalella azteca* (Amphipoda: Talitridae) were relatively common. Large numbers of *S. frontale* were also taken at the downstream site in late spring and summer. The narrow-

winged damselfly *Argia* (Coenagrionidae) was common at both stations in summer. Midges were generally most abundant in early fall; *Glyptotendipes* was the most abundant organism at both stations, and *Chironomus* was numerous in summer and early fall. In Red Rock Creek, *S. frontale* was generally common at both stations through early fall. The mayfly *Tricorythodes* (Trichorythidae) and net-spinning caddisfly *Cheumatopsyche* (Hydropsychidae) were common in spring. *Argia*, *Chironomus*, and *Larsia* (Chironomidae) were common in summer. *Glyptotendipes* was the most common organism at the downstream station but was rare upstream. Species richness at the four sites was lower in winter (4–14) than during other seasons (9–26). Densities in Greasy Creek varied from $108/m^2$ in winter to $3,185/m^2$ in early fall. Corresponding densities in Red Rock Creek were 37 and 8,856 individuals per square meter. Densities increased in spring and summer and decreased in late fall. Maximum densities corresponded to the reproductive season of several species of midges and mayflies. Although conductivities in Greasy Creek were high during summer over abandoned oil fields (maximum = 9,072 μmhos/cm) and dissolved oxygen concentrations declined to 0.9 mg/L, species richness and diversity in the stream did not seem to be limited by these factors; the macroinvertebrate assemblage of Red Rock Creek was similar to that in Greasy Creek. Minimum dissolved oxygen concentration in Red Rock Creek was 3.3 mg/L and maximum conductivity was 2,145 μmhos/cm.

Ontario

Williams et al. (1974) studied the life history of the crayfish *Cambarus fodiens* in an ephemeral stream in southern Ontario. Individuals remained in burrows during winter and early spring when current velocities were high. In early April, all forms except egg-bearing females began to emerge. Egg-bearing females emerged in late April when velocities decreased and young were released soon thereafter; this delayed emergence avoided downstream drift of young. Upon desiccation of pools in late May, crayfish retreated to burrows where they remained until the following April. As the ground water level receded, burrows were extended to keep the resting station immediately below the surface of the water. Other organisms in the burrows included nematodes, oligochaetes, ostracods, copepods, amphipods, and midges. [Crayfish burrows may be the only refuge for these organisms during summer drought in streams lacking permanent pools.]

Seasonal variations in macroinvertebrate assemblages were examined by Williams and Hynes (1976, 1977) in two Ontario streams; one was ephemeral, the other intermittent. Taxa present in the ephemeral stream included Tricladida (flatworms), Nematoda, Oligochaeta, Gastropoda (snails), Ostracoda, Copepoda, Amphipoda, Decapoda (crayfish), Hydracarina (water mites), Ephemeroptera, Hemiptera, Trichoptera, Coleoptera, and Diptera. The fauna of the intermittent creek was similar, but also included leeches, a fingernail clam, a cladoceran (water flea), stoneflies, and dragonflies. Permanent pools and moist areas allowed habitation of this stream by a much wider variety of species than in the ephemeral reach, especially those species with fairly long aquatic stages. Pools also allowed survival of certain species that would not normally be able to live in a lotic environment and at the same time supported colonization by many purely lentic forms. High temperatures in the pools encouraged rapid growth of algae and enabled certain invertebrates to reach maturity quickly. Riparian vegetation was considered important in moisture retention. Vertical migration into the substrate (as deep as 60 cm) was common in many taxa. Animals were divided into three sequential groups, based on the water conditions found during the year: (1) a fall–winter stream fauna that appeared shortly after flow commenced in the fall and reproduced successfully before cessation of flow, (2) a spring fauna that reproduced in pools following cessation of flow, and (3) a summer fauna, of terrestrial species normally found on the banks, that colonized the dry stream bed. Organisms in intermittent streams coped with summer drought by eight basic means. Two of these required emigration (habitation of nearby perennial streams and aerial adulthood). The others included habitation of remaining pools, under rocks, under leaf litter, buried shallow, buried deep, or as cohabitants of crayfish burrows; major taxa using these methods were listed. The authors noted that although intermittent and ephemeral streams are environmentally unstable the species composition of abundant macroinvertebrates found therein is stable. This was attributed to specialized adaptations and the exclusion of competitors.

Invertebrate drift in adjacent intermittent and perennial streams in southern Ontario was compared by Dance and Hynes (1979). The streams drained watersheds of equal size and had similar water quality. The basin of the intermittent stream was heavily agricultural with little residual forest, whereas the watershed of the perennial stream was 34% forested and had far less agriculture. As a probable result of these differences, flow ceased in the intermittent reach in summer. Water temperatures were higher in the intermittent stream than in the perennial reach. Calculated total dry weights of all taxa drifting past stations on the perennial stream during the 13-month study were 39.54 kg on the upstream site and 43.70 kg on the downstream site. Corresponding values on the intermittent stream were 37.12 and 181.87 kg. Midges dominated drift of the perennial stream. Midges also

drifted in the intermittent stream, but other flies, water boatmen, and especially snails were substantial components of the drift. Certain species were stream-specific or differed considerably in abundance in the two streams. Drift and discharge were correlated in the perennial stream but not in the intermittent reach, suggesting that organisms inhabiting intermittent streams are resistant to drift. [Nevertheless, drift in intermittent streams was appreciable, especially in consideration of the shorter duration of flow.]

Victor et al. (1981) compared drift of ostracods in adjacent intermittent and perennial streams in southern Ontario. Ostracods composed more than 90% of crustacean drift in both streams. Ten species were present in the drift of the perennial stream. Three of these also appeared in the intermittent stream, as well as one additional species not found in the former. No overall correlation existed between discharge and drift, but resumption of flow in the intermittent stream elicited substantial drift of ostracods from formerly isolated pools. Calculated total numbers of ostracods drifting past upstream and downstream stations in the perennial stream during the 13-month study were 9,100 (910 g) and 48,450 (3,610 g), respectively. Corresponding values in the intermittent stream were 6,850 (710 g) and 41,090 (4,470 g).

South Dakota

McCoy and Hales (1974) documented insect assemblages in three intermittent and five perennial streams on the eastern side of the Coteau de Prairies, South Dakota. Collections were made before cessation of flow. In riffles, 60 benthic taxa were collected; 42 taxa occurred in intermittent and 58 occurred in perennial streams. Only two species (a stonefly and a caddisfly) were found exclusively in the intermittent streams; however, many species achieved higher densities in the intermittent streams than in the perennial streams. In pools, 21 taxa were collected; 7 were in intermittent streams, 1 of which (a dragonfly) was absent from perennial streams. [These findings indicate that intermittent streams are preferred or more suitable habitats for some insects.]

Texas

Campbell and Clark (1982) described macroinvertebrate assemblages in Aquilla Creek, an intermittent Texas stream; in Hackberry Creek, a formerly intermittent tributary augmented by sewage effluents; and in Aquilla Creek below the confluence of Hackberry Creek. Sampling was conducted quarterly during 1980 under base-flow conditions. On the intermittent reach, sampling was confined to a long-stagnant pool with substrate composed of silty mud, clay, and leaf litter. Pools and riffles were sampled on the flowing reaches. Invertebrate species richness and abundance were lowest on the intermittent section, apparently due to the absence of riffle habitat at the time of sampling; taxa present in the pool included abundant oligochaetes and low densities of pond snails (Physidae), the mayfly *Caenis*, and the midges *Bezzia*, *Chaoborus*, *Polypedilum*, *Chironomus*, and *Tanypus*. A survey of additional upstream sites during August 1980 indicated that although within-pool variability of macroinvertebrates in the intermittent reach was negligible, large differences existed among pools, especially of the types and abundances of flies. These differences were attributed to isolation effects and substrate and size differences among pools. Isolation of water in different areas of the intermittent streambed following cessation of flow resulted in the formation of unique and diverging pool assemblages in close proximity. In flowing reaches, changes in assemblage structure were gradual. The August survey also provided information on effects of sewage effluents on the biota of intermittent streams. In a stagnant, intermittent pool upstream from the sewage outfall on Hackberry Creek, a diverse fauna included flies, annelids, molluscs, dragonflies, beetles, horsehair worms, and true bugs. Below the outfall, the only organisms found were annelids and dipteran larvae, mostly *Chironomus*; species richness gradually increased downstream from the outfall.

Studies conducted by Stewart et al. (1973), Cloud and Stewart (1974), Vaught and Stewart (1974), and Rhame and Stewart (1976) are largely peripheral to this review except that they indicate that the Brazos River below Possum Kingdom Reservoir, Texas, was inhabited by a diverse and productive macroinvertebrate assemblage. Before construction of the dam, the Brazos River had intermittent flows and presumably possessed a depauperate fauna, based on comparisons with nearby unaltered streams. Minimum flows (about 0.5 cm) from leakage around the turbines and floodgates of Possum Kingdom Dam were believed to be responsible for increases in species richness and productivity of macroinvertebrates. [This conclusion obliquely illustrates the need for minimum intermittent flows on impounded intermittent streams to maintain their unique faunal assemblages. At the opposite extreme, headwater flood-control impoundments with fixed spillways may completely preclude discharges needed to maintain permanent pools in intermittent streams during dry seasons and thereby create ephemeral habitats.]

Zimbabwe

Reestablishment of macroinvertebrates following the dry season was monitored in an intermittent stream near Harare, Zimbabwe, by Harrison (1966). [The stream resembled those in the southern Great Plains.]

Reestablishment was rapid following resumption of flow; oligochaetes, nematodes, cyclopoid copepod zooplankters, and midge larvae appeared within the first 10 days. A midge and a blackfly recolonized the stream following resumption of flow, but both species disappeared after 2 months. Taxa typical of perennial streams were present in pools within 1 month and within 4–6 weeks in riffles. Faunal composition was essentially the same as in nearby perennial streams within 2 months of resumption of flow. Rapid recovery of various taxa was attributed to resting eggs, aestivation in subsurface and moist habitats, deep burrowing, and immigration of flying adults from perennial streams.

Fishes

Summary

Fishes are perhaps the best studied component of intermittent streams. Nevertheless, little definitive information exists on their importance in the dynamics of Great Plains ecosystems or on their response to effects of habitat alterations in intermittent streams.

Fish faunas of intermittent streams in the south-central Great Plains are dominated by a relatively small assemblage of fishes that is highly tolerant of variable and extreme physical conditions. The most common and abundant fishes in intermittent prairie streams are green sunfish, orangespotted sunfish, longear sunfish, orangethroat darter, black bullhead, red shiner, redfin shiner, central stoneroller, bluntnose minnow, fathead minnow, sand shiner, and blackstripe topminnow. (Scientific names of these and other fishes mentioned in this chapter are listed in the Appendix.) Many other species, including popular sport fishes such as largemouth bass, bluegill, and white crappie also are present in intermittent streams, but their abundances are usually low. Other fishes (e.g., white bass and white sucker) inhabit intermittent streams temporarily for spawning or during high flow. However, temporary use of intermittent streams has not been adequately assessed to date, largely because sampling with standard techniques is difficult at high-water stages. Knowledge of fishes in intermittent streams is mostly a product of seining during low-water periods.

Although fish assemblages in intermittent streams tend to consist of relatively few species, abundances are often high. Resident species are primarily small and feed on algae, detritus, and invertebrates; therefore, they may constitute an important trophic link between intermittent streams and terrestrial and downstream habitats when consumed by wildlife or swept downstream. In addition, some evidence suggests that intermittent streams may be important nursery areas before cessation of flow. Much like coastal salt marshes, they are warm (and thereby permit rapid growth), support abundant invertebrate forage, and lack large predatory fish. These conditions promote high survival and growth rates of early life history stages. However, neither the magnitude nor the relative importance of these phenomena has been quantified.

Although ephemeral streams and dewatered areas of intermittent streams are rapidly repopulated by some species after flow resumes, permanent pools are the most important feature of intermittent streams with respect to fishes. Not only do they contain the only available water for fish during dry periods, but the deeper water provides protection from aerial and terrestrial predators. The value of a pool to fishes is directly related to its size and the volume of water it contains. Large pools are not only capable of harboring more individuals than small pools, but because they are more physicochemically stable, they can accommodate species less tolerant of environmental extremes. Increases in pool size and frequency (i.e., in habitat volume, heterogeneity, and physical stability) are the main factors responsible for the typical progressive downstream increases in fish species richness and production from a stream's headwaters to its mouth. Schlosser (1987) demonstrated that downstream increases in pool development, habitat volume, and heterogeneity in warmwater streams resulted in increased fish species richness and density and hypothesized that fish assemblages occupying large, deep, well-developed pools with high habitat heterogeneity are relatively stable over time. Accordingly, manipulations that decrease size or frequency of permanent pools (e.g., channelization, clearing and snagging, siltation) decrease habitat availability and stability and deleteriously affect fish assemblages in intermittent streams. Similarly, removal of riparian vegetation from banks of intermittent streams decreases shading and promotes instability through wider temperature extremes.

Reference Annotations

Longitudinal gradients in fish species richness and discharge variation were examined in 15 river systems in Illinois, Missouri, Ohio, and Wyoming by Horwitz (1978). Prairie rivers with intermittent headwaters were included. Headwaters exhibited highest variability in flow and lowest fish richness. Headwater fish species richness was lowest in river systems with the most variable headwaters. [This synthesis consolidated the underlying assumption regarding fish assemblages in intermittent headwaters—these assemblages are depauperate because few species can withstand the instability inherent in these habitats. Factors that increase the physical instability of intermittent headwaters include loss of pools through channelization, increased fluctuation in flow resulting from headwater impound-

ments that discharge through fixed spillways, and increased fluctuation in temperature resulting from loss of riparian vegetation. These factors exacerbate reduction of species richness.]

Arizona

Factors affecting survival of speckled dace, longfin dace, and Mexican stoneroller in intermittent streams of the Chiricahua Mountains, Arizona, were examined by John (1964). Deaths during summer drought were caused directly by desiccation in ephemeral pools and indirectly by starvation in permanent pools. Temperatures did not rise to lethal levels in permanent pools. Flash floods did not affect adult fish but resulted in death of many young of the year carried downstream into ephemeral reaches. Predation by belted kingfishers (*Megaceryle alcyon*), blackneck garter snakes (*Thamnophis cyrtopsis*), and raccoons was not considered to be a major cause of mortality.

Lewis and Burraychak (1979) documented effects of effluents from open-pit copper mines on the biota of an intermittent stream in central Arizona. Longfin dace were largely unaffected by typical effluent discharges, but abundances of mosquitofish were greatly reduced and desert suckers were extirpated. These results were attributed to the synergistic effects of toxic metals, low dissolved oxygen concentrations, high temperatures in isolated pools, substrate compaction, and elimination of permanent pools by sedimentation.

British Columbia

Significant seasonal use of ephemeral and intermittent streams by cutthroat trout, steelhead, and coho salmon in British Columbia was documented by Hartman and Brown (1987). They provided guidelines for logging designed to minimize disturbance of these habitats. [Analogous use of intermittent streams in the Great Plains by important sport or food fishes has not been quantitatively documented, but studies adequately assessing the possibility have not been conducted.]

California

Erman and Hawthorne (1976) estimated that 39%–47% of adult rainbow trout in Sagehen Creek, California, spawned in an intermittent tributary, whereas perennial tributaries attracted only 10%–15%. The remainder spawned in upper reaches of the main stream. Early runoff and high peak flows were considered major factors influencing the intermittent stream's attractiveness to spawning fish. Exclusion of brook trout by lack of water in fall may have enhanced the value of the stream to young rainbow trout. Emigration of young was promoted by fluctuations in discharge signaling the onset of intermittency (Erman and Leidy 1975). The authors called for enlightenment of foresters and land-use managers regarding the importance of intermittent streams as fish nursery areas. [Use of intermittent streams in the Great Plains for spawning by important sport or food fishes also may be significant, but no research has been conducted to quantify the phenomenon.]

Genetic variability of threespine sticklebacks in an intermittent stream system in southern California was studied by Bell and Richkind (1981). Although confined to pools during dry periods, sticklebacks dispersed upstream and downstream in intermittent reaches during floods, thereby accomplishing gene flow. However, an impoundment on the stream imposed a barrier to upstream movement and gene flow, resulting in asymmetrical gene flow with a downstream bias. Upstream stickleback populations were genetically isolated by the impoundment.

Illinois

The following fishes were reported to occur in intermittent headwaters of prairie streams in Illinois by Thompson and Hunt (1930): creek chubsucker, white sucker, central stoneroller, bluntnose minnow, creek chub, silverjaw minnow, golden shiner, and black bullhead. The rigorous conditions and physical extremes present in such streams were noted, as was the enhanced tolerance of this assemblage to physiological stress.

The fish assemblage of Smiths Branch, a small warmwater stream in Illinois, was monitored by Larimore et al. (1959) before, during, and after a severe drought that (along with rotenoning of remaining pool refugia) resulted in the extirpation of all fish. Flow often ceases in the stream for short periods during late summer and fall, and high temperatures and low dissolved oxygen concentrations occasionally result in fish deaths in isolated pools, but this drought resulted in a cessation of flow from early August through January. Reestablishment of fishes began as soon as flow resumed. Upstream ingression was initially limited to the lowermost pools above the stream mouth until full flow was resumed. Within 2 weeks of resumption of full flow, 21 of 29 fishes considered as occuring regularly had moved into most of the stream course. In order of decreasing distances moved upstream (in parentheses), these were bluntnose minnow, white sucker, creek chub, and silverjaw minnow (10.1 km); redfin shiner, orangethroat darter, northern hog sucker, and blackside darter (9.1 km); common shiner, spotfin shiner, and creek chubsucker (6.6 km); central stoneroller, golden redhorse, and green sunfish (4.3 km); rainbow darter, sand shiner, and rock bass (3.2 km); smallmouth bass, and suckermouth minnow (2.1 km); and greenside darter and fantail darter (0.5 km). Black bullheads, yellow bullheads, johnny darters, and quillback reentered the stream by the end of the summer following the drought. Longear

sunfish did not repopulate the stream until 2 years later; blackstripe topminnows, hornyhead chubs, and golden shiners were still absent after 4 years. Adults that reentered the stream following resumption of flow reproduced successfully, which resulted in an assemblage dominated by young of the year.

Indiana

The only fish found by Clifford (1966) in an ephemeral Indiana stream was the creek chub. Adults spawned in the stream during high flows in spring. Young of the year remaining in the stream died when the stream went dry. Emigration before cessation of flow was not assessed.

Iowa

Starrett (1950) documented distributions of fishes in Boone County, Iowa, including those found in intermittent headwater prairie streams. Species dominating permanent pools of intermittent headwaters were bigmouth shiner, creek chub, central stoneroller, and black bullhead. Other species present were hornyhead chub, blacknose dace, common shiner, sand shiner, Topeka shiner, brassy minnow, fathead minnow, bluntnose minnow, stonecat, johnny darter, fantail darter, green sunfish, orangespotted sunfish, and brook stickleback. Absence of other species common in perennial streams was attributed to high water temperatures and low dissolved oxygen concentrations during late summer in the permanent pools.

Paloumpis (1958) monitored fish assemblages in Squaw Creek, an intermittent tributary of the Skunk River in central Iowa. The stream typically ceases flowing from late summer or fall through late winter. Twenty-nine species were collected, nine of which were considered abundant or common (quillback, common carp, creek chub, common shiner, bigmouth shiner, red shiner, fathead minnow, green sunfish, and orangespotted sunfish). White suckers used the stream for spawning, and creek chubs and common shiners increased in abundance during their spawning seasons. Although deep pools provided refuge during droughts, presence of many species was attributed to immigration from the Skunk River. After a severe winter drought during which winter kill occurred in many pools, only four species (bigmouth shiner, red shiner, bluntnose minnow, and creek chub) were present in the stream. However, 13 species were collected within 3 weeks of resumption of flow.

Kansas

Metcalf (1959) described fish faunas of isolated pools in several intermittent streams of southern Kansas. Six collections were made in Crab Creek extending from near its mouth to the uppermost site containing water. Pools near the mouth were shaded by trees and were as large as 10 m wide and 30 m long. Upper sites were extremely shallow and averaged 3 m long and 1.5 m wide; they were in bluestem pasture. At the uppermost site (site 1), only small green sunfish were present. Species additions at consecutive sites downstream were (site 2) black bullhead, red shiner, and redfin shiner; (site 3) longear sunfish and bluntnose minnow; (site 4) yellow bullhead, white crappie, orangespotted sunfish, largemouth bass, orangethroat darter, logperch, and golden redhorse; (site 5) brook silverside and blackstripe topminnow; and (site 6) spotted sucker. Abundances of green sunfish and black bullhead decreased markedly at downstream sites (sites 4–6). An analogous progression was found on upper Beaver Creek, which had only five species. In order of appearance (from upstream to downstream) these were black bullhead, green sunfish, orangespotted sunfish, red shiner, and redfin shiner. Two collections were made in a small tributary of Grouse Creek. One, from isolated pools near the source of the creek, contained the following species: orangespotted sunfish (48%), black bullhead (45%), red shiner (5%), and green sunfish (2%). The other collection, taken about 6.4 km downstream, contained the following fishes: orangespotted sunfish (40%), red shiner (30%), green sunfish (20%), and blackstripe topminnow (10%). Although species richness in intermittent creeks was low, densities were often high. Green sunfish and black bullheads rapidly colonized ephemeral reaches after flow began; upstream movements of unnamed species were also reported. Other species taken from isolated pools of larger intermittent streams (number of collections in parentheses) were longnose gar (6), gizzard shad (3), river carpsucker (1), smallmouth buffalo (6), bigmouth buffalo (1), common carp (4), bigeye shiner (4), ghost shiner (1), bluntface shiner (4), emerald shiner (1), rosyface shiner (2), mimic shiner (4), golden shiner (1), slim minnow (6), bullhead minnow (1), fathead minnow (1), central stoneroller (5), mosquitofish (9), flathead catfish (1), channel catfish (1), slenderhead darter (2), channel darter (3), spotted bass (4), black crappie (1), bluegill (4), and freshwater drum (1).

Responses of fish assemblages to several years of extreme drought were examined by Deacon (1961) in the upper Neosho and Marais des Cygnes rivers of eastern Kansas. Although typically perennial, these streams showed discontinuous flows for several years during the drought. Reestablishment of populations in these rivers may be analogous to patterns typical of intermittent streams. As the drought progressed, assemblages began to resemble fish faunas more typical of nearby intermittent streams; that is, they were dominated by black bullhead, spotted bass, largemouth bass, white crappie, red shiner, rosyface shiner, bluntnose minnow,

mimic shiner, and slender madtom. Abundances of species typical of larger streams (e.g., channel catfish, flathead catfish, freshwater drum, blue sucker) and riffle-dwelling species (e.g., gravel chub, Neosho madtom, slenderhead darter) declined. With resumption of flow, mobile habitat-generalists (e.g., channel catfish, flathead catfish, freshwater drum, river carpsucker, longnose gar) rapidly repopulated the streams. Ingressing and surviving species produced exceptionally large year-classes in the first year of permanent flow. Species occupying restricted habitats, especially the riffle-dwellers, were slowest to reestablish after the drought. Species captured before the drought but not collected following resumption of flow were highfin carpsucker, common shiner, hornyhead chub, and johnny darter; however, their absence was attributed to specific habitat requirements affected by environmental degradation not associated with the drought.

Deacon and Metcalf (1961) classified drought tolerance of fishes based on their distributions in the Wakarusa River system of Kansas following the drought years of the early 1950's. Many perennial streams in the region flowed intermittently during this period. Species unaffected by intermittency were the red shiner, black bullhead, green sunfish, and fathead minnow. White sucker, redfin shiner, bluntnose minnow, and logperch were not severely affected by intermittency or quickly recolonized areas from which they were extirpated during drought. Fishes having lesser capacity for survival or dispersal were creek chub, Topeka shiner, suckermouth minnow, orangethroat darter, and central stoneroller. Slender madtoms, common shiners, hornyhead chubs, and johnny darters survived in only a few refugia and showed no tendency for dispersal after drought.

In a largely taxonomic and zoogeographic treatise on the fish fauna of the Kansas River system, Metcalf (1966) listed the following species as characteristic of intermittent and ephemeral low-order streams of the Great Plains: creek chub, sand shiner, red shiner, fathead minnow, central stoneroller, plains killifish, black bullhead, green sunfish, orangespotted sunfish, and orangethroat darter. Metcalf implied that habitation of these streams was generally temporary, the fish moving up into them from more permanent streams during periods of low flow.

The Kansas Department of Health and Environment (1981) conducted a study to determine effects of floodwater retarding impoundments on the biota of intermittent and ephemeral streams in Kansas. Curtailed funding precluded a comprehensive and detailed analysis of the data, but preliminary analyses suggested that most fishes (including sport fishes) were more abundant both above and below impoundments than in unimpounded streams. However, 12 species were less abundant below impoundments than in control streams, including the creek chub, duskystripe shiner, sand shiner, and fathead minnow. The Topeka shiner, bigmouth shiner, and fantail darter were absent below impoundments. Eight species less abundant above impoundments than in control streams were the creek chub, suckermouth minnow, redfin shiner, Topeka shiner, sand shiner, fathead minnow, white sucker, and longear sunfish; the bigmouth shiner and blackstripe topminnow were absent above impoundments.

Cross et al. (1985) examined effects of decreased flows in streams of western Kansas by comparing past and present fish collections. Species currently present in the now-intermittent upper Arkansas River include fathead minnow, suckermouth minnow, red shiner, sand shiner, central stoneroller, common carp, mosquitofish, gizzard shad, plains killifish, black bullhead, channel catfish, green sunfish, orangespotted sunfish, and largemouth bass. Although many of these fishes have declined in abundance and distribution in the upper Arkansas River, they are able to tolerate intermittent flows. Species now absent in the upper Arkansas River, but present in lower perennial reaches or in the perennial upper Cimarron River, include flathead chub, redbelly dace, plains minnow, speckled chub, Arkansas River shiner, emerald shiner, bullhead minnow, bluntnose minnow, river carpsucker, white sucker, golden redhorse, smallmouth buffalo, flathead catfish, freshwater drum, bluegill, white crappie, orangethroat darter, and Arkansas darter. Intermittent flows are apparently of decreased suitability for these species in western Kansas.

Eberle et al. (1986) compared past and recent (1983–84) assemblages of fishes and selected aquatic macroinvertebrates inhabiting Big Creek, an intermittent stream in western Kansas. The stream is impounded by a number of dams and low-water bridges. Agricultural runoff increased turbidity and siltation in the creek. Fish kills were common in pools as a result of low dissolved oxygen concentrations. Collections in 1983–84 yielded 27 species. Effects on the fish assemblage were difficult to assess because previous collections included surveys as recent as 1981; many species listed as previously collected (total = 26) were introduced to impoundments on the stream. At least five fishes were considered extirpated from the system (American eel, Topeka shiner, common shiner, hornyhead chub, and stonecat). The eel was excluded from the stream by dams; the other species probably were eliminated by changes in water and habitat quality.

Kentucky

The now widely accepted correlation between fish species richness and stream order was established by Kuehne (1962) through study of fish distributions in Buckhorn Creek, Kentucky. Headwaters of the system (orders 1 and 2) are intermittent. The creek chub was

the only fish collected at a 1st-order site; additions at 2nd-order sites were white sucker, northern hog sucker, central stoneroller, silverjaw minnow, striped shiner, bluntnose minnow, greenside darter, rainbow darter, fantail darter, johnny darter, and arrow darter. Two catostomids, seven cyprinids, three centrarchids, three percids, and one atherinid were present only in perennial 3rd- and 4th-order reaches.

Hoyt (1970) monitored diets of silverjaw minnows in an intermittent stream in Kentucky. The species did not forage selectively; rather, it fed on the most readily available organisms. Midge larvae constituted the primary food organism, and mayfly nymphs and water fleas were considered secondary. Occasional foods were beetles, caddisflies, stoneflies, isopods (aquatic sow bugs), amphipods (scuds), oligochaetes (aquatic earthworms), snails, fingernail clams, copepod zooplankters, crayfish, ants, wasps, and bees. Seasonal variation in diet depended largely on availability. During late summer and early fall when flow ceased, metamorphosis and emergence of most insect larvae and depletion of food organisms in isolated pools by overexploitation caused a shift to consumption of large amounts of detritus. Accordingly, the condition of the fish declined.

Lotrich (1973) examined longitudinal variation in growth, production, and composition of fish assemblages in a 3rd-order intermittent stream system in eastern Kentucky. Species richness by order was additive; only creek chubs inhabited 1st-order streams. Additions in 2nd-order streams were central stoneroller, arrow darter, johnny darter, fantail darter, rainbow darter, northern hog sucker, and white sucker. Silverjaw minnows, rosefin shiners, striped shiners, bluntnose minnows, rock bass, longear sunfish, and smallmouth bass were added at 3rd-order sites. Annual production values (gram dry weight per linear-meter) of the fish assemblages were 2.35 g in 1st-order, 2.36 g in 2nd-order, and 3.29 g in 3rd-order streams. Trends of increasing species richness and production with order were attributed to increased physical stability at downstream sites—a function of pool size and pool frequency. Pool widths, and their linear proportion per stream interval, increased with stream order. [Accordingly, habitat alterations that decrease the size or frequency of pools in intermittent streams, such as channelization, clearing and snagging, and siltation, would promote development of fish assemblages resembling those in lower-order reaches (i.e., would result in decreased species richness and production).]

Louisiana

Guillory (1982) examined the longitudinal gradient in fish assemblages of Thompson Creek, Louisiana, from its headwaters to its mouth on the Mississippi River. Of 68 species inhabiting the 80-km stream, only 13 were present in the intermittent headwaters; a general increase in the number of species in a downstream direction was apparent. Species that inhabited headwaters included green sunfish, bluegill, longear sunfish, blacktail shiner, striped shiner, longnose shiner, creek chub, blacktail redhorse, mosquitofish, blackspotted topminnow, yellow bullhead, and black bullhead. Creek chubsuckers and black bullheads were found only in intermittent headwaters; creek chubs, blackspotted topminnows, mosquitofish, and yellow bullheads were more abundant in headwaters than elsewhere. Environmentally rigorous and structurally simple intermittent headwater habitats resulted in an assemblage of few species. More diverse assemblages inhabited stable and structurally complex habitats downstream.

Missouri

Hanson and Campbell (1963) examined distribution of fishes in Perche Creek, a northern Missouri stream with intermittent headwaters. The diverse headwater fish fauna (23 species) included minnows, suckers, catfishes, sunfishes, and darters. The anomalously high fish species richness, abundance, and biomass was a function of numerous large, deep, permanent pools in the headwaters resulting from beaver (*Castor canadensis*) dams; pools impounded by beaver were considerably larger than nearby natural pools. The river carpsucker was found only in beaver pools in the headwaters. Pool size was positively correlated with species richness. [These findings illustrate the importance of large, deep, permanent pools in intermittent streams, regardless of their origin; stream alterations that destroy or diminish pools would probably degrade fish faunas.]

Nebraska

Maret and Peters (1980) collected fishes throughout the Salt Creek basin of southeastern Nebraska. Many sampling sites were on intermittent prairie creeks. Fathead minnows, sand shiners, green sunfish, black bullheads, and red shiners were common and abundant inhabitants of isolated permanent pools. Other fishes collected from intermittent streams were bluegill, common carp, creek chub, and yellow bullhead. Low species richness in these habitats was attributed to the harsh environmental conditions. Survival of highly tolerant fishes in many streams was possible only because of the presence of permanent pools, including those formed by beaver dams.

Ohio

In their seminal study of an intermittent Ohio stream, Stehr and Branson (1938) were concerned largely with invertebrates; however, they noted the presence of common shiners, central stonerollers, and bluntnose minnows in lower reaches of the stream. Many young

fish were observed there in spring and were believed to be swept downstream into the receiving river by floods. Fish were observed only in the immediate vicinity of the mouth of the stream during summer. Relatively quiet water, lack of large predators, and abundant food influenced distribution. As many as 600 young fish were counted in an 8-m^2 pool.

Wickliff (1945) collected the following species from isolated pools on Blacklick Creek, an intermittent prairie stream in Ohio: johnny darter, fantail darter, orangethroat arter, bluntnose minnow, creek chub, golden shiner, redfin shiner, central stoneroller, white sucker, green sunfish, yellow bullhead, black bullhead, and redfin pickerel. Although mortality of these fishes was observed in ephemeral pools, permanent pools allowed survival of these species during summer drought. Flooding did not result in downstream displacement; rather, movement was largely lateral to the rising stream banks.

Mortality of fish during summer drought was monitored in six small pools of a 1st-order intermittent stream in Ohio by Tramer (1977). Heavy mortality of white suckers, blackside darters, and johnny darters occurred 5 days before pools dried up. Mortality of goldfish, creek chub, suckermouth minnow, redfin shiner, common shiner, sand shiner, fathead minnow, orangethroat darter, and least darter were low until pool volumes declined to about 20 L. Most mortality was during daylight when temperatures were high and dissolved oxygen concentrations were low. The pattern was reversed for goldfish, which died principally at night. Fish survived in only 1 of the 6 pools; about 24 juvenile cyprinids and orangethroat darters remained in two footprint-sized puddles when a thunderstorm reflooded the creekbed. In all pools, young juveniles (millimeter total length) were the last to die. Ancillary observations suggested that a few small fishes survived complete disappearance of surface pools. One pool not used in the study was observed to dry up with the apparent loss of all fish. About 18 h later a brief shower left about 250 mL of water in the pool; 2 small least darters and 1 orangethroat darter were found therein. Apparently, these fish survived by burrowing into the sediment. Predation by terrestrial animals was rare (except immediately before pool desiccation) but scavenging of moribund individuals (primarily by killdeer, *Charadrius vociferus*, and green-backed herons, *Butorides striatus*) was intense. Sampling 1 year later showed that all species except the fathead minnow and least darter had repopulated the area; in addition, redfin pickerel, spotfin shiner, blackstripe topminnow, and green sunfish were present.

Griswold et al. (1978) compared fish assemblages in channelized and unchannelized reaches of several perennial streams in Ohio and Indiana. However, a severe drought in 1974 caused cessation of flow in one of their study streams, the Little Auglaize River, Ohio. The entire channelized portion of the stream was dry for nearly 2 months; accordingly, all fish within the reach died. The unchannelized control site upstream retained isolated pools into which fish congregated and survived the drought. [The situation would seem to be analogous to channelization of an intermittent stream.]

Oklahoma

Moore and Mizelle (1938) conducted an ichthyofaunal survey of Stillwater Creek and its tributaries in north-central Oklahoma as a 1,300-ha headwater flood-control impoundment, Lake Carl Blackwell, was nearing completion on the stream. The stream was then intermittent from its headwaters to Stillwater, where sewage effluent augmented flow. A low-water dam was present at the sewage outfall. Seven fishes lived in permanent pools of the headwaters (golden shiner, red shiner, fathead minnow, black bullhead, green sunfish, orangespotted sunfish, and white crappie), and 21 species inhabited the stream below Stillwater. The greater species richness below Stillwater was due partly to perennial flow resulting from sewage effluent, but absence of some species in the headwaters may have been caused by the low-water dam that precluded temporary use of upstream reaches during periods of flow by common large-river fishes from the Cimarron River.

The fish assemblages of the Stillwater Creek system were reexamined by Cross (1950) 10 years after the survey of Moore and Mizelle (1938). The character of the stream was altered considerably by (1) completion and filling of Lake Carl Blackwell; (2) an increase in the stream's sewage load, about half of which was untreated (causing occasional oxygen deficiencies and fish kills); (3) maintenance and stabilization of flow-through, formerly intermittent, reaches above Stillwater by continuous release from the reservoir; (4) reduced turbidity resulting from settling in the reservoir; and (5) introduced fishes. Sampling sites included the mouth of the stream on the Cimarron River; a station several kilometers below the sewage outfall; the sewage outfall and low-water dam area; the tailwaters of Lake Carl Blackwell; Boomer Creek, a tributary impounded by many low-water dams and a large headwater dam near Stillwater; and Little Stillwater Creek, an undisturbed intermittent tributary. Collections from permanent pools in Little Stillwater Creek yielded the same species, except white crappie, reported by Moore and Mizelle (1938) from the former headwaters that were inundated by Lake Carl Blackwell and also included the sand shiner and yellow bullhead. An abundant, rich fish assemblage was present at the mouth of the stream, including many large-river species common in the

Cimarron River. Fish were often abundant at the station several kilometers below the sewage outfall, except under extreme low-water conditions when fish kills occurred. Fish were collected at the sewage outfall below the low-water dam only during high-water conditions; major fish kills occurred there whenever discharge declined. In Boomer Creek—essentially a series of ponds—the highly modified fish fauna was composed primarily of introduced lake species. The tailwaters of Lake Carl Blackwell were inhabited by many of the species originally found in the area, as well as a number of introduced fishes stocked in the reservoir. Cross (1950) concluded that the alterations to the system resulted in a net benefit to the fish fauna because of increased flow and fertility despite the frequent mortality in some segments. Total abundance was higher than in the earlier survey and a popular sport fishery (primarily for white bass, channel catfish, flathead catfish, black bullheads, and common carp) developed in the stream. However, Cross (1950) warned that the effects of sewage effluent would be devastating were it not for the enhanced stability in flow resulting from continuous discharges from Lake Carl Blackwell. [Lake Carl Blackwell is a relatively large headwater impoundment possessing capabilities for subsurface releases. Smaller headwater impoundments, with lower capacities and fixed spillways, preclude virtually all downstream discharges during dry seasons except after exceptionally heavy rainfall; formerly permanent pools may dry completely. Spring Creek, which flows into Stillwater Creek about 500 m above its confluence with the Cimarron River, was described by Cross (1950) as ecologically and physically unique for the region. This spring-fed, clear creek consisted principally of long shallow stretches of fast water flowing over a sand bottom. Since 1950, numerous small impoundments have been constructed on Spring Creek and its tributaries. It is now highly intermittent and indistinguishable from other small, turbid, impounded creeks in the area.]

Two large pools (combined area = 0.07 ha) of Salt Creek, an intermittent tributary of the Arkansas River in north-central Oklahoma, were treated with rotenone by Elkin (1954) in July 1954. Maximum depths were 1.4 and 1.5 m, and average depths of both were 0.8 m. Pool depths and volumes and abundant riparian vegetation maintained relatively low water temperatures (21–28°C). Accordingly, species richness was high; 36 species were collected. A high proportion of sport fishes was collected, but this was considered an artifact of sample site distribution; forage and rough fishes were thought to be more abundant in larger (1- to 2-ha) pools not sampled. Biomass density in the two pools combined was 272 kg/ha. Back-calculated growth rates of largemouth bass, green sunfish, longear sunfish, warmouth, yellow bullhead, black bullhead, river carpsucker, common carp, and freshwater drum were higher than in the Illinois River, a perennial tributary of the Arkansas River in eastern Oklahoma. Growth rates of spotted bass, white crappie, black crappie, bluegill, flathead catfish, and black buffalo were similar in both streams, and only channel catfish, golden redhorse, river redhorse, and gizzard shad grew at a slower rate in Salt Creek than in the Illinois River. Growth rate of spotted bass in Salt Creek was exceeded by conspecifics in only one of eight other Oklahoma streams for which data were available. Other species collected from the pools were spotted gar, longnose gar, spotted sucker, redfin shiner, mimic shiner, ghost shiner, suckermouth minnow, bluntnose minnow, slim minnow, mosquitofish, brook silverside, redear sunfish, orangespotted sunfish, slenderhead darter, channel darter, logperch, and orangethroat darter. [Although Salt Creek is a relatively large intermittent stream and ceases to flow for relatively short periods, its fish assemblage illustrates the importance of large, deep, well-shaded pools to survival of fish during periods of environmental stress.]

Harrel et al. (1967) examined the relation between stream order and fish species richness in the Otter Creek drainage basin of north-central Oklahoma. The basin is a 6th-order, intermittent prairie system. Collections were made in June after 8 months of continuous flow and again in September, 1 week after resumption of flow. Twenty species were taken: golden shiner, fathead minnow, black bullhead, bluegill, green sunfish, mosquitofish, orangespotted sunfish, red shiner, longear sunfish, largemouth bass, white crappie, suckermouth minnow, channel catfish, river carpsucker, flathead catfish, emerald shiner, plains minnow, longnose gar, yellow bullhead, and gizzard shad. June collections yielded 18 species. Seven species were collected from 3rd-order, 12 from 4th-order, 16 from 5th-order, and 17 from 6th-order streams. Number of species at individual sites varied from 1 to 5 in 3rd-order, 6 to 11 in 4th-order, 8 to 13 in 5th-order, and 5 to 13 in 6th-order streams. Except for a single flathead catfish taken at a 5th-order site, all species collected at lower-order sites also were taken from each higher-order stream. September collections yielded 16 species. Five species were collected from 3rd-order, 8 from 4th-order, 14 from 5th-order, and 15 from 6th-order streams. Numbers of species at individual sites varied from 0 to 4 at 3rd-order sites, 1 to 8 at 4th-order sites, 8 to 13 at 5th-order sites, and 9 to 12 at 6th-order sites. Except for a single yellow bullhead at a 5th-order site, all species collected at lower-order sites also were taken from all higher-order streams. Fishes taken in June but absent in September were suckermouth minnow, flathead catfish, plains minnow, and longnose gar; their absence was attributed to the short period since resumption of flow.

Fishes present only in September were yellow bullhead and gizzard shad; however, both were taken within relatively short distances of the receiving stream, Skeleton Creek. Few fishes were believed to have survived in permanent pools of Otter Creek because of stagnation and intense predation. Repopulation was probably by migration from Skeleton Creek and from overflowing adjacent farm ponds.

Smith and Powell (1971) collected fish during summer in Brier Creek, a stream with open, intermittent headwaters and wooded, perennial lower reaches entering Lake Texoma in southern Oklahoma. Species diversity and richness increased downstream. Fishes collected in the intermittent reaches were golden shiner, common carp, central stoneroller, fathead minnow, bullhead minnow, red shiner, bigeye shiner, river carpsucker, brook silverside, blackstripe topminnow, green sunfish, orangespotted sunfish, bluegill, longear sunfish, redear sunfish, largemouth bass, spotted bass, black bullhead, yellow bullhead, and orangethroat darter. Fishes highly tolerant of physicochemical extremes and dominant in ephemeral and intermittent reaches were green sunfish, orangespotted sunfish, fathead minnow, red shiner, and black bullhead. The green sunfish and fathead minnow were specifically identified as species colonizing ephemeral areas whenever possible. In the lower perennial sections, all of the preceding species, except river carpsucker, were collected, as well as blacktail shiner, silver chub, mosquitofish, inland silverside, gizzard shad, threadfin shad, freshwater drum, white bass, white crappie, and logperch. These additional fishes (as well as common carp) were considered temporary inhabitants of the stream that entered it from the reservoir.

Collections of fishes in the South Canadian River, Oklahoma, by Matthews and Maness (1979) suggested that red shiners and plains minnows increased in abundance during summer, whereas abundances of Arkansas River shiners and emerald shiners decreased. Laboratory experiments showed that tolerance to heat stress was higher in red shiners and plains minnows than in the other species. Red shiners and plains minnows are common inhabitants of headwater reaches of intermittent streams in the Great Plains. Their success in these environmentally rigorous habitats indicates resistance to environmental flux through increased physiological tolerance. Similar adaptation is likely widespread in other species characteristic of intermittent headwaters.

Fish assemblages and habitat of lower Walnut Bayou, Oklahoma, were characterized by Stinnett et al. (1981) in response to a request for participation in the assessment of proposed channelization of the stream. Walnut Bayou is a 5th-order, unimpounded, intermittent tributary of the Red River. Based on the presence of permanent pools, sampling efforts were confined to a 16.7-km reach. The reach was separated into upper and lower sections based on differences in land use. The 10.0-km upper section was bordered by agricultural lands; disjunct stands of streamside hardwoods occurred along 46% of the reach. The 6.7-km lower section was bordered by dense bottomland hardwood forest over 95% of the reach. A total of 236 pools, composing 5.2 surface ha, was estimated in the 16.7-km reach. Two pools in each section were intensively sampled for fish in August 1980. Assemblages at all sites were dominated numerically by red shiners, mimic shiners, and mosquitofish. Juvenile sunfishes (orangespotted, longear, bluegill) were present at some sites. Small numbers of common carp, river carpsucker, and smallmouth buffalo dominated biomasses. Other species collected included spotted gar, longnose gar, gizzard shad, ghost shiner, suckermouth minnow, bullhead minnow, channel catfish, black bullhead, flathead catfish, green sunfish, warmouth, white crappie, and freshwater drum. The fish fauna consisted of species with broad ranges of tolerance, poor sportfish quality, and an affinity for sluggish, backwater areas. At the two upstream sites there were 19 and 39 fish per square meter and biomasses of 9.9 and 12.9 g/m^2; at both downstream sites there were 60 fish per square meter and biomasses of 25.4 and 26.0 g/m^2. The disparity between reaches was attributed to differences in adjacent land use or allochthonous inputs, downstream migration during drought, or proximity to the receiving system. Extrapolation of estimates to the entire study reach resulted in a total biomass estimate of 683 kg and a total abundance of 1,688,000 fish. Pool volumes were correlated with fish abundances ($r^2 = 0.80$) and biomasses ($r^2 = 0.88$), but the relations were not significant ($P > 0.05$) because of the small sample size. Permanent pools were considered critical to the existence of fish in Walnut Bayou. A cover letter referred to additional collections in May 1981 during high flow that yielded four additional species (yellow bullhead, white bass, bluntnose minnow, and sand shiner). Anecdotal information suggested the stream harbors a sizeable white bass spawning run.

Heat death of orangethroat darters was observed in small intermittent pools of Brier Creek in southern Oklahoma by Matthews et al. (1982). Deaths occurred during a severe heat wave when daily air temperature exceeded 40°C for several weeks. Water temperature in the affected pools was 38–39°C and dissolved oxygen concentration was 5 mg/L. Conspecifics survived in larger pools where temperature was 34.5°C. [Large and deep (i.e., high volume) pools, because of their greater inherent stability, offer more secure refuge during periods of environmental stress than do small pools.]

Studies conducted by Power et al. (1985) were largely ancillary to our review except for their observation that redistribution, presumably downstream, of central

stonerollers and largemouth bass in a southern Oklahoma intermittent stream occurred only during extremely severe spates.

Ross et al. (1985) examined long-term (1969–81) trends in fish assemblages and abundances in Brier Creek, Oklahoma, encompassing an exceptionally hot and dry summer (1980), when heat death of some species was evident. [This was the same stream studied by Smith and Powell (1971).] Of the common species present in 1969, all but one (spotted bass) were taken in 1981, suggesting that the harsh 1980 summer had no lasting effect on overall assemblage stability. However, headwater assemblages underwent considerable flux in rank order of species abundances compared to downstream reaches, and midreach assemblages in 1981 resembled headwater assemblages before 1980. Nevertheless, species composition in the headwaters was highly persistent, suggesting that species present were well adapted to harsh environments. Suggested causes for the degree of stability and persistence shown by Brier Creek fishes included (1) high intrinsic rates of increase, which allow rapid repopulation by survivors of environmental perturbation; (2) high vagility, which permitted rapid return to areas dewatered during summer drought; (3) resistance through highly developed local refuge-seeking behavior, which maintained populations during drought; and (4) resistance through increased physiological tolerance to environmental change.

Information presented by Matthews et al. (1986) in a range-extension account showed that the orangebelly darter, slough darter, and bigscale logperch inhabited permanent pools of intermittent streams in southern Oklahoma.

Matthews (1987) compared physicochemical tolerancesand selectivities of fishes to determine how these characteristics influence their geographic and local ranges. Minnows considered "prairie stream" species (red shiner, Arkansas River shiner, blacktail shiner, emerald shiner, Red River shiner, sand shiner) were compared to congeners either wholly restricted to benign, clear, upland streams or considered most successful in such habitats (bigeye shiner, duskystripe shiner, Ozark minnow, redfin shiner, rosyface shiner, striped shiner). The prairie group was more tolerant of high temperatures and low dissolved oxygen concentrations than the upland group and also showed greater avoidance of low oxygen concentrations in an experimental gradient. Fishes common in Brier Creek (green sunfish, orangespotted sunfish, bluegill, longear sunfish, central stoneroller, red shiner, bigeye shiner, blacktail shiner, blackstripe topminnow, orangethroat darter, and bigscale logperch), an intermittent stream in southern Oklahoma, all exhibited high tolerance of thermal stress, except the bigscale logperch, which was restricted to lower reaches of the stream. However, a significant relation existed between longitudinal position in the stream and tolerance of hypoxia. The findings support the concept that fish assemblages in intermittent prairie streams are dictated primarily by physical constraints such as high temperature and low dissolved oxygen concentration as opposed to biotic interactions such as competition and predation.

Ontario

Only two species of fish (creek chub and brook stickleback) comprising seven individuals were found by Williams and Hynes (1976) in an ephemeral stream in Ontario. Neither species reproduced in the stream. The stream was recolonized by immigration from downstream permanent habitats during flow. A nearby intermittent stream was inhabited by nine species including minnows, suckers, sticklebacks, and daters.

In their 13-month study of invertebrate drift in adjacent intermittent and perennial streams in southern Ontario, Dance and Hynes (1979) also tabulated drift of "Pisces fry" collected in their nets. Calculated dry weights of fish larvae drifting past two stations, which were 2 km apart on the perennial reach, were 1,040 g at the upstream station and 50 g at the downstream station. Corresponding values for the intermittent stream were 3,440 g and 240 g. [These data indicate that drift of ichthyoplankton in intermittent streams is at least comparable to that in perennial streams and suggest that intermittent reaches may be important nursery areas. The diminution of ichthyoplanktonic drift between stations was greater on the perennial reach, which suggested that predation may have been less intense in the intermittent stream. Alternatively, spawning activity may have been more intense in lower reaches of the intermittent stream.]

Williams and Coad (1979) described life histories of fishes that inhabited one ephemeral and two intermittent streams in southern Ontario. Only a few brook sticklebacks and creek chubs lived in the ephemeral stream during periods of flow; these were stranded when the stream dried. Brook sticklebacks, bluntnose minnows, fathead minnows, and white suckers were common and abundant in both intermittent streams throughout the year. Less abundant but common, species were the least darter, johnny darter, creek chub, and brassy minnow. Northern redbelly dace, longnose dace, common shiner, and Iowa darter were rare or infrequent. The depauperate fish faunas were attributed to rigorous environmental conditions in the streams; species successfully invading these habitats must be either physiologically tolerant or capable of migration. Adult white suckers and creek chubs were present only during early spring, suggesting that they moved into streams from perennial reaches to spawn and emigrated shortly thereafter. Because these streams warmed more

rapidly than larger streams, spawning was possible at an earlier date. Young fish thereby enjoyed a longer growing season in a nursery environment with abundant invertebrate food and few large predators.

Panama

Angermeier and Karr (1983) examined factors affecting fish assemblages in tropical streams of Panama. Fish biomasses and densities were lowest in the one intermittent stream studied out of a total of nine streams. Species richness within feeding guilds was also correlated with stream size. Deep pools were preferred habitats of many species despite higher food densities in shallow areas apparently because of the refuge they afford from predatory birds and mammals. The paucity of fish in the intermittent stream was attributed to intense predation.

South Dakota

McCoy and Hales (1974) documented fish assemblages in two intermittent and five perennial streams on the eastern side of the Coteau de Prairies, South Dakota. Collections were made in June before cessation of flow in the intermittent streams. Twenty-two species were collected from the perennial streams, of which 12 also occurred in the intermittent streams: brassy minnow, central stoneroller, common shiner, bluntnose minnow, fathead minnow, blacknose dace, creek chub, white sucker, black bullhead, brook stickleback, green sunfish, and johnny darter.

Texas

The relation between fish assemblages and stream order in the Plum Creek drainage of south-central Texas was examined by Whiteside and McNatt (1972). Collections made from January through April yielded 27 species. Species richness and diversity increased as stream order increased through 4th-order streams; lower values in the 5th-order stream were attributed to sampling difficulties and the possibility that some species moved upstream to spawn. Ranges and total number of species taken at replicate sites in each stream order were as follows: 1st-order, 0–4, 6; 2nd, 0–5, 10; 3rd, 1–12, 19; 4th, 5–12, 19; and 5th, 12–12, 12. The longitudinal trend in fish distribution was additive; generally, new species were added rather than replaced as order increased. The lowest stream order in which each species occurred was as follows: 1st-order – red shiner, mosquitofish, green sunfish, bluegill, central stoneroller, warmouth; 2nd-order – golden shiner, black bullhead, blacktail shiner, largemouth bass, sailfin molly, bullhead minnow; 3rd-order – longear sunfish, pugnose minnow, white crappie, orangespotted sunfish, slough darter, flathead catfish, gizzard shad, blackstripe topminnow; 4th-order – redear sunfish, gray redhorse, channel catfish, spotted bass; and 5th-order – speckled chub. Low species richness in the headwaters was attributed to rigorous environmental conditions, limited space and food, and low habitat diversity.

A fish faunal survey of Big Sandy Creek in eastern Texas by Evans and Noble (1979) illustrated the importance of large permanent pools in intermittent streams. Of 46 species collected in the 4th-order system, 22 were taken at a 1st-order intermittent site (blackspot shiner, ribbon shiner, redfin shiner, golden shiner, pugnose minnow, creek chub, creek chubsucker, blackspotted topminnow, mosquitofish, black bullhead, yellow bullhead, tadpole madtom, bluntnose darter, slough darter, warmouth, longear sunfish, bluegill, spotted sunfish, green sunfish, dollar sunfish, redfin pickerel, and pirate perch). The percentage of the entire fish fauna of the stream present in the 1st-order headwaters was much higher than found in other stream systems described in the literature. The unusually rich headwater assemblage was attributed to the geological character of the watershed, which allowed formation of exceptionally large, deep, and stable headwater pools conducive to survival of fishes during summer drought.

Virginia

Matthews and Styron (1981) tested the hypothesis that fish species of intermittent headwaters were more tolerant of abrupt physicochemical change than species restricted to perennial habitats. The mountain redbelly dace, a headwater cyprinid of the Roanoke River drainage in Virginia, was compared to three river cyprinids (rosefin shiner, white shiner, and crescent shiner) for tolerance of abrupt changes in dissolved oxygen concentration, temperature, and pH. Fantail darters collected in headwater reaches were compared to two river species (riverweed darter and Roanoke darter) and to conspecifics captured in a perennial stream for tolerance of low dissolved oxygen concentration. Fish were tested by direct transfer; endpoints were death (caused by pH) or loss of equilibrium (caused by the temperature or dissolved oxygen concentration). In all comparisons, headwater forms were more tolerant than those restricted to more environmentally stable perennial habitats. Results suggested that fish of physically rigorous, intermittent headwaters are more tolerant of physicochemical changes than are species inhabiting environmentally benign and relatively more stable habitats. Physicochemical tolerances seem to correlate with upstream limits of distributions in small watersheds and thus may relate directly to the pattern of longitudinal zonation of species that is observed in many stream systems.

Wildlife

A wealth of information exists on various aspects of the natural history, distribution, and ecology of birds and

mammals in the south-central Great Plains, but little of it addresses the specific importance of intermittent streams as wildlife habitats. Less information is available on amphibians and reptiles, but it is likely that intermittent and ephemeral streams are important habitats for some species (Stehr and Branson 1938; Ireland 1976; Fitzgerald 1978; Stout 1982). For example, western terrestrial garter snakes (*Thamnophis elegans*) prey on stranded trout fry in permanent pools along intermittent streams in California (Erman and Leidy 1975). Comparisons of habitats along intermittent streams to riparian communities found throughout the United States along perennial waterways are possible given similar physiognomic and ecological characteristics of the vegetation (Teskey and Hinckley 1978).

This section is less definitive than the previous chapters, reflecting the paucity of data specific to wildlife that use intermittent streams. In some cases, we draw on research on permanent streams and riparian habitats from outside the south-central Great Plains, but our use of that literature is restricted to emphasizing just how little is known about the importance of intermittent streams to wildlife.

Wildlife professionals, as well as the general public generally recognize the importance of riparian areas to aquatic and terrestrial wildlife resources, regardless of the permanency of water flow (Oklahoma Chapters of The Wildlife Society and the American Fisheries Society 1982). Thomas et al. (1979) noted that riparian areas are critical wildlife habitats because (1) they provide a permanent or seasonal source of water; (2) plant biomass is typically greater than in surrounding communities because of increased soil moisture, which increases structural diversity; (3) interspersion of riparian and upland communities can maximize wildlife diversity (i.e., edge effect); (4) they provide greater diversity of microhabitats, including wildlife nesting and feeding sites; and (5) they constitute important movement and migratory corridors. Detrimental influences include road and campground construction, extensive grazing by livestock, uncontrolled logging, and alterations to stream flow (e.g., diversion for irrigation, impoundments, or channelization; Thomas et al. 1979).

Birds

The importance of riparian vegetation along permanent streams or rivers to birds has been widely reported (Carothers et al. 1974; Stevens et al. 1977; Stauffer and Best 1980). Generally, indices of bird community complexity (e.g., species richness and diversity) are related to structural complexity of the vegetation, which tends to be maximized in riparian communities. For example, bird species diversity can be positively correlated with foliage height diversity (Karr and Roth 1971; Carothers et al. 1974), percentage of vegetative cover (Karr and Roth 1971), and width of the riparian zone (Stauffer and Best 1980; McCauley 1983). Although riparian vegetation along intermittent streams likely will be less developed and structurally less complex than along permanent streams, it will still offer a richer floral habitat than surrounding uplands.

Knopf (1985) compared bird communities in associated upland and riparian habitats near permanent streams along an altitudinal gradient in northeastern Colorado and observed 82% of all bird species in riparian areas. A total of 111 and 124 bird species was encountered in each of 2 years of study, and of the total, 38%–46% of species were observed only in riparian areas. The most speciose bird assemblages were observed in cottonwood (*Populus* spp.)–willow (*Salix* spp.) riparian communities below 2,000 m on the eastern plains of Colorado, and they tended to be most stable between years (i.e., low species turnover). In addition, Knopf (1985) noted that interchange between elevations was greatest for riparian communities, which perhaps was indicative of their importance as dispersal corridors (Knopf 1986). Although this study concentrated on perennial streams, northeastern Colorado has numerous ephemeral and intermittent streams, and we expect similar patterns of bird distribution in such areas, particularly in the vicinity of permanent pools during the dry season from mid-summer to mid-fall.

In portions of the south-central Great Plains, intensive irrigation for agriculture has altered the water table to such a degree that flow dynamics of streams and rivers and riparian communities have been altered. For example, Knopf (1986) reported that an increased water table around the South Platte River in northeastern Colorado has changed it from an intermittent river (i.e., flowing 4–6 months per year in spring and early summer) to a perennially flowing river. As a result, riparian vegetation has increased in this part of Colorado, which seems to be aiding dispersal of birds having greater eastern forest affinity (e.g., red-headed woodpecker [*Melanerpes erythrocephalus*], brown thrasher [*Toxostoma rufum*], and orchard oriole [*Icterus spurius*]) than prairie affinity (Knopf 1986). Eighty-three bird species were observed in the riparian zone – 38 with regularity and 30 obligate. In contrast, nine bird species were observed in the associated rangeland. Knopf's (1986) surveys indicated only a 37% similarity between riparian and rangeland avifaunas. Developing riparian communities in northeastern Colorado are also important habitats for waterfowl (Anatidae; presumably migrants and some breeders), northern bobwhite (*Colinus virginianus*), introduced wild turkey (*Meleagris gallopavo*), and the exotic ring-necked pheasant (*Phasianus colchicus*; Knopf 1986).

Vegetational composition in riparian areas, particularly in eastern Colorado and further west, has been

altered by the invasion of the exotic Russian olive (*Elaeagnus angustifolia*), which tends to prefer moist sites and may displace native climax species (Christensen 1963; Knopf and Olson 1984; Knopf 1986). Although Russian olive can provide good wildlife food and cover and can increase the width of the riparian zone in the short-term, forest stands dominated by Russian olive tend to support bird and small mammal assemblages that are less speciose than those in native riparian stands (Knopf and Olson 1984). Initially, Russian olive provides a useful mid-story canopy (i.e., 10–12 m) to bird species (Knopf and Olson 1984), but it has been predicted that it will eventually displace larger trees such as cottonwood, which will further alter bird distribution (Knopf 1986).

Riparian woodlands along intermittent streams in the Cross Timbers (i.e., interspersed tall-grass prairie and post oak [*Quercus stellata*]–blackjack oak [*Q. marilandica*] forests) of central Oklahoma are important year-round habitats for birds. McCauley (1983) recorded 61 bird species using this habitat type during a 1-year period. Fifty-one species were year-round residents, only three were considered migrants, and seven were winter transients. Evenness of the bird community and feeding guild richness was correlated positively with tree densities. Diversity of the avifauna was maximized when the width of the riparian zone was 38 and 98 m (78 m considered optimum) and trees were 2.5–7.5 cm diameter at breast height (McCauley 1983). Bird diversity tended to be highest in narrow riparian zones between 38–98 m, but the variety of feeding guilds was maximized at intermediate widths. Similarly, Stauffer and Best (1980) concluded that bird species richness was positively correlated with width of the riparian zone in Iowa.

Along with structural and size characteristics of the riparian habitats, several authors have noted that associated habitats affect bird distribution. In Arizona, riparian areas are more heavily used by spring migrants, particularly insectivorous species, than upland areas (Stevens et al. 1977). Granivorous species preferred adjacent shrubland; however, heavy grazing on the uplands reduced the suitability of this habitat for granivores, as reflected in lower species diversity of passerines (Stevens et al. 1977). Overall, grazing decreased bird diversity of the riparian-upland complex. Similarly, Carothers et al. (1974) postulated that disparate population sizes and average bird weights in two types of riparian habitats in Arizona were in part due to the difference in feeding opportunities afforded by associated habitats.

Intermittent streams of the south-central Great Plains tend to flow in spring and early summer. At this time, they are important to migrants and species establishing breeding territories. Guild richness of bird assemblages along intermittent streams in central Oklahoma is highest in spring (McCauley 1983). Breeding species encounter optimum cover, nesting sites, and food and water availability in spring along intermittent streams. Although waterfowl do not nest in large numbers in the south-central Great Plains (Sutton 1967), intermittent streams likely provide important stopover sites for migrating waterfowl, particularly dabbling ducks (*Anas* spp.). In the north-central Great Plains (e.g., North Dakota), intermittent streams, which also flow during spring and early summer, are important nesting sites for blue-winged teal (*A. discors*) and mallards (*A. platyrhynchos*). Hubbard (1979) noted that densities of breeding dabbling ducks along intermittent streams in North Dakota varied from 5.60 to 6.11 pairs per hectare over a 2-year period. Densities of breeding pairs were highest during years of high water flow. Hubbard (1979) concluded that intermittent streams were excellent breeding habitats during spring flow because of the relatively large ratio of shoreline per unit area of water. Land adjacent to the best breeding sites was (1) generally idle or untilled uplands with herbaceous cover 0.15 m tall; (2) had limited emergent vegetation; and (3) provided abundant submerged vegetation, which is optimum foraging habitat for broods (Hubbard 1979).

Mammals

Riparian corridors can be important to mammals because such corridors typically provide food, protective and thermal cover, and water in greater abundance than upland areas (Thomas et al. 1979). Unlike birds, few mammals are so restricted in their local distributions to be considered obligate riparian species. Large, mobile species may regularly frequent or prefer riparian areas, but they also use upland sites with regularity. Higher population densities of small mammals may occur in riparian than in upland areas.

In a semi-arid region such as the south-central Great Plains, availability of water is critical. During periods of high flow in the spring, water is likely abundant throughout the landscape (e.g., free water and preformed water in forage); therefore, intermittent streams may not represent a critical water resource. As water becomes limited in availability with increased evaporation and decreased precipitation in summer, permanent pools that remain in the intermittent streambeds are likely critical water sources for a variety of vertebrates. Such pools will be more critical in dry years than in wet years. Although such relations may seem obvious, we lack specific data on the use of permanent pools in intermittent streambeds as water sources for terrestrial vertebrates.

The cottonwood–willow riparian areas of eastern Colorado and western Kansas are generally richer in mammals than upland areas (Beidleman 1978;

Fitzgerald 1978); however, it does not seem that any mammal is unique to the riparian corridor (Moulton 1978). Beidleman (1978) compared species richness in a variety of eastern Colorado riparian areas and generally found decreased richness in the eastern and southeastern part of the State, which is an area of stream intermittency. Nevertheless, 81 species and subspecies of amphibians, reptiles, birds, and mammals were noted in the eastern and southeastern sites. Beidleman (1978) noted that the riparian sites with greatest diversity had a wide range of tree ages, but they tended to be mature forests with some standing, dead individuals. Adequate water availability and a lack of saltcedar (*Tamarix pentandra*), an invasive exotic tree with little wildlife value, were also important (Beidleman 1978).

Flooding may occasionally perturb mammalian communities that inhabit areas around intermittent streams. Flooding also influences development of vegetation along intermittent and ephemeral waterways (Ware and Penfound 1949). Large, mobile species would simply be displaced temporarily without significant effects to their populations. Conversely, small mammals could be adversely affected, although no specific information is available for the south-central Great Plains. Short-term flooding (i.e., 1–8 days) seems to have little effect on population characteristics of white-footed mice (*Peromyscus leucopus*; Stickel 1948; Ruffer 1961). Many small mammals are arboreal and can avoid floods. In contrast, long-term flooding (e.g., 21+ days) was responsible for a 70% decrease in *Peromyscus* numbers in southeastern Texas (McCarley 1959). It is likely that small mammals that inhabit areas around intermittent streams in the south-central Great Plains have adopted strategies to avoid harmful effects of periodic flooding.

Riparian habitats typically do not account for a high percentage of the landscape area, but their irregular, weblike patterns enhance connectivity of disjunct habitats (Noss 1987). Some mammals, such as white-tailed deer (*Odocoileus virginianus*) and mule deer (*O. hemionus*), prefer the cover afforded by riparian habitat and use these areas for security and as travel corridors (Fitzgerald 1978; Severson 1981; Menzel 1984). Therefore, riparian corridors likely aid gene flow and dispersal of individuals (Soule and Simberloff 1986), but no specific information on intermittent prairie streams is available. In addition, areas along any watercourse likely provide a greater variety of food resources to mammals; for example, raccoons exploit crayfish and other organisms along intermittent streams (Momot 1966). Fox squirrels (*Sciurus niger*), eastern and desert cottontails (*Sylvilagus floridanus* and *S. audubonii*), and coyotes (*Canis latrans*) can be common in these areas (Fitzgerald 1978).

Channelization of waterways and associated destruction of riparian habitats generally have a negative effect on wildlife (Heller 1973; Barclay 1980). In Oklahoma, channelization seems to have the greatest influence on richness and abundance of small mammals, amphibians, reptiles, and birds (Barclay 1980). In Mississippi and Alabama, beaver, muskrat (*Ondatra zibethicus*), mink (*Mustela vison*), and raccoon were more numerous on or near unchannelized stream segments than on or near channelized segments (Gray and Arner 1977). Channelization destroyed denning sites for muskrats and beaver and decreased the aquatic-based food resources of raccoon and mink (Gray and Arner 1977). Whereas some studies have demonstrated little effect of channelization on small mammals (Ellis 1976), others have shown decreases in number or diversity (Possardt and Dodge 1978). The extent of detrimental effects to small mammals or birds (Carothers and Johnson 1975) seems to depend on the extent of destruction and subsequent regeneration of riparian vegetation (Ellis 1976).

Conclusions

Intermittent streams are unique habitats essential to the structure and function of ecosystems of the southern Great Plains. Their presence is critical to fish and wildlife populations in the region, an area where perennial streams are rare and separated by great distances. Modification of intermittent streams by channelization, removal of riparian vegetation, grazing, construction of headwater impoundments, siltation, and domestic and industrial effluents is highly deleterious to these sensitive habitats and their biota and significantly degrades the quality of adjacent terrestrial habitats. Accordingly, these perturbations insidiously affect the quality of human life in the region. Enhanced protection of intermittent streams is an essential component of natural resource management in the southern Great Plains, especially in consideration of the neglect of these critically important habitats in past and present land-use planning.

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Appendix. Common and Scientific Names of Fishes Mentioned in the Text.

Common name	Scientific name	Common Name	Scientific Name
American eel	*Anguilla rostrata*	Golden redhorse	*Moxostoma erythrurum*
Arkansas darter	*Etheostoma cragini*	Golden shiner	*Notemigonus crysoleucas*
Arkansas River shiner	*Notropis girardi*	Goldfish	*Carassius auratus*
Arrow darter	*Etheostoma sagitta*	Gravel chub	*Hybopsis x-punctata*
Bigeye shiner	*Notropis boops*	Gray redhorse	*Moxostoma congestum*
Bigmouth buffalo	*Ictiobus cyprinellus*	Green sunfish	*Lepomis cyanellus*
Bigmouth shiner	*Notropis dorsalis*	Greenside darter	*Etheostoma blennioides*
Bigscale logperch	*Percina macrolepida*	Highfin carpsucker	*Carpiodes velifer*
Black buffalo	*Ictiobus niger*	Hornyhead chub	*Nocomis biguttatus*
Black bullhead	*Ictalurus melas*	Inland silverside	*Menidia beryllina*
Black crappie	*Pomoxis nigromaculatus*	Iowa darter	*Etheostoma exile*
Blacknose dace	*Rhinichthys atratulus*	Johnny darter	*Etheostoma nigrum*
Blackside darter	*Percina maculata*	Largemouth bass	*Micropterus salmoides*
Blackspot shiner	*Notropis atrocaudalis*	Least darter	*Etheostoma microperca*
Blackspotted topminnow	*Fundulus olivaceus*	Logperch	*Percina caprodes*
Blackstripe topminnow	*Fundulus notatus*	Longfin dace	*Agosia chrysogaster*
Blacktail redhorse	*Moxostoma poecilurum*	Longear sunfish	*Lepomis megalotis*
Blacktail shiner	*Notropis venustus*	Longnose dace	*Rhinichthys cataractae*
Blue sucker	*Cycleptus elongatus*	Longnose gar	*Lepisosteus osseus*
Bluegill	*Lepomis macrochirus*	Longnose shiner	*Notropis longirostris*
Bluntface shiner	*Notropis camurus*	Mexican stoneroller	*Campostoma ornatum*
Bluntnose darter	*Etheostoma chlorosomum*	Mimic shiner	*Notropis volucellus*
Bluntnose minnow	*Pimephales notatus*	Mosquitofish	*Gambusia affinis*
Brassy minnow	*Hybognathus hankinsoni*	Mountain redbelly dace	*Phoxinus oreas*
Brook stickleback	*Culaea inconstans*	Neosho madtom	*Noturus placidus*
Brook silverside	*Labidesthes sicculus*	Northern hog sucker	*Hypentelium nigricans*
Brook trout	*Salvelinus fontinalis*	Orangebelly darter	*Etheostoma radiosum*
Bullhead minnow	*Pimephales vigilax*	Orangespotted sunfish	*Lepomis humilis*
Central stoneroller	*Campostoma anomalum*	Orangethroat darter	*Etheostoma spectabile*
Channel catfish	*Ictalurus punctatus*	Ozark minnow	*Notropis nubilis*
Channel darter	*Percina copelandi*	Pirate perch	*Aphredoderus sayanus*
Coho salmon	*Oncorhynchus kisutch*	Plains killifish	*Fundulus zebrinus*
Common carp	*Cyprinus carpio*	Plains minnow	*Hybognathus placitus*
Common shiner	*Notropis cornutus*	Pugnose minnow	*Notropis emiliae*
Creek chub	*Semotilus atromaculatus*	Quillback	*Carpiodes cyprinus*
Creek chubsucker	*Erimyzon oblongus*	Rainbow darter	*Etheostoma caeruleum*
Crescent shiner	*Notropis cerasinus*	Rainbow trout	*Salmo gairdneri*
Cutthroat trout	*Salmo clarki*	Red River shiner	*Notropis bairdi*
Desert sucker	*Catostomus clarki*	Red shiner	*Notropis lutrensis*
Dollar sunfish	*Lepomis marginatus*	Redear sunfish	*Lepomis microlophus*
Duskystripe shiner	*Notropis pilsbryi*	Redfin pickerel	*Esox americanus*
Emerald shiner	*Notropis atherinoides*	Redfin shiner	*Notropis umbratilis*
Fantail darter	*Etheostoma flabellare*	Ribbon shiner	*Notropis fumeus*
Fathead minnow	*Pimephales promelas*	River carpsucker	*Carpiodes carpio*
Flathead catfish	*Pylodictis olivaris*	River redhorse	*Moxostoma carinatum*
Flathead chub	*Hybopsis gracilis*	Riverweed darter	*Etheostoma podostemone*
Freshwater drum	*Aplodinotus grunniens*	Roanoke darter	*Etheostoma roanoka*
Ghost shiner	*Notropis buchanani*	Rock bass	*Ambloplites rupestris*
Gizzard shad	*Dorosoma cepedianum*	Rosefin shiner	*Notropis ardens*

Common name	Scientific name	Common Name	Scientific Name
Rosyface shiner	*Notropis rubellus*	Spotted sucker	*Minytrema melanops*
Sailfin molly	*Poecilia latipinna*	Spotted sunfish	*Lepomis punctatus*
Sand shiner	*Notropis stramineus*	Steelhead	*Salmo gairdneri*
Silver chub	*Hybopsis storeriana*	Stonecat	*Noturus flavus*
Silverjaw minnow	*Ericymba buccata*	Striped shiner	*Notropis chrysocephalus*
Slender madtom	*Noturus exilis*	Suckermouth minnow	*Phenacobius mirabilis*
Slenderhead darter	*Percina phoxocephala*	Tadpole madtom	*Noturus gyrinus*
Slim minnow	*Pimephales tenellus*	Threadfin shad	*Dorosoma petenense*
Slough darter	*Etheostoma gracile*	Threespine stickleback	*Gasterosteus aculeatus*
Smallmouth bass	*Micropterus dolomieui*	Topeka shiner	*Notropis topeka*
Smallmouth buffalo	*Ictiobus bubalus*	Warmouth	*Lepomis gulosus*
Southern redbelly dace	*Phoxinus erythrogaster*	White bass	*Morone chrysops*
Speckled chub	*Hybopsis aestivalis*	White crappie	*Pomoxis annularis*
Speckled dace	*Rhinichthys osculus*	White shiner	*Notropis albeolus*
Spotfin shiner	*Notropis spilopterus*	White sucker	*Catostomus commersoni*
Spotted bass	*Micropterus punctulatus*	Yellow bullhead	*Ictalurus natalis*
Spotted gar	*Lepisosteus oculatus*		

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16. Abstract (Limit: 200 words)

Intermittent streams are unique habitats essential to the structure and function of southern Great Plains ecosystems. Unfortunately, they are usually regarded as poor habitat for fish and wildlife and have thus received little protection. This review assesses the physiocochemical characteristics of these inherently unstable streams and summarizes the literature of their flora, macroinvertebrates, fish, reptiles, amphibians, birds, and mammals. The flora is largely unstudied and inconspicuous with microalgae as the primary producers. Macroinvertebrates dominate the stream fauna. Fish assemblages are dominated by high abundances of relatively few species that can tolerate the seasonally extreme conditions. Little published information exists on the value of these systems to other wildlife, but as portions of riparian systems, they provide critical habitat for many species. Modification of intermittent streams by channelization, removal of riparian vegetation, grazing, construction of headwater impoundments, siltation, and domestic and industrial effluents severely degrades these aquatic systems and nearby terrestrial habitat. Enhanced protection of intermittent streams is an essential component of natural resource management in the southern Great Plains.

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